DOCUMENT RESUME

ED 021 740 24 SE 004 647

By- Balabanian, Norman; Kirwin, Gerald J.

DIODE AND DIODE CIRCUITS, A PROGRAMMED TEXT.

Syracuse Univ., N.Y. Dept. of Electrical Engineering.
Spons Agency- Office of Education (DHEW), Washington, D.C. Bureau of Research.
Report No- 4
Bureau No- BR-5-0796
Pub Date 64
Contract- OEC-4-10-102
Note- 177p.
EDRS Price MF-$0.75 HC-$7.16
Descriptors- *COLLEGE SCIENCE, ELECTRICITY, *ELECTRONICS, *ENGINEERING EDUCATION, *INSTRUCTIONAL MATERIALS, PHYSICAL SCIENCES, *PROGRAMED INSTRUCTION, TEXTBOOKS, UNDERGRADUATE STUDY
Identifiers- United States Office of Education, University of Syracuse

This programed text on diode and diode circuits was developed under contract with the United States Office of Education as Number 4 in a series of materials for use in an electrical engineering sequence. It is intended as a supplement to a regular text and other instructional material. (DH)

BR 5-0796
PA 24

No. 4

A Programmed Text

DIODE AND DIODE CIRCUITS

by

Norman Balabanian and Gerald J. Kirwin

Electrical Engineering Department

Syracuse University

#4

A Programmed Text

DIODE AND DIODE CIRCUITS

by

Norman Balabanian and Gerald J. Kirwin
Electrical Engineering Department
Syracuse University

Contract No. 4-10-102 OE
U.S. Office of Education

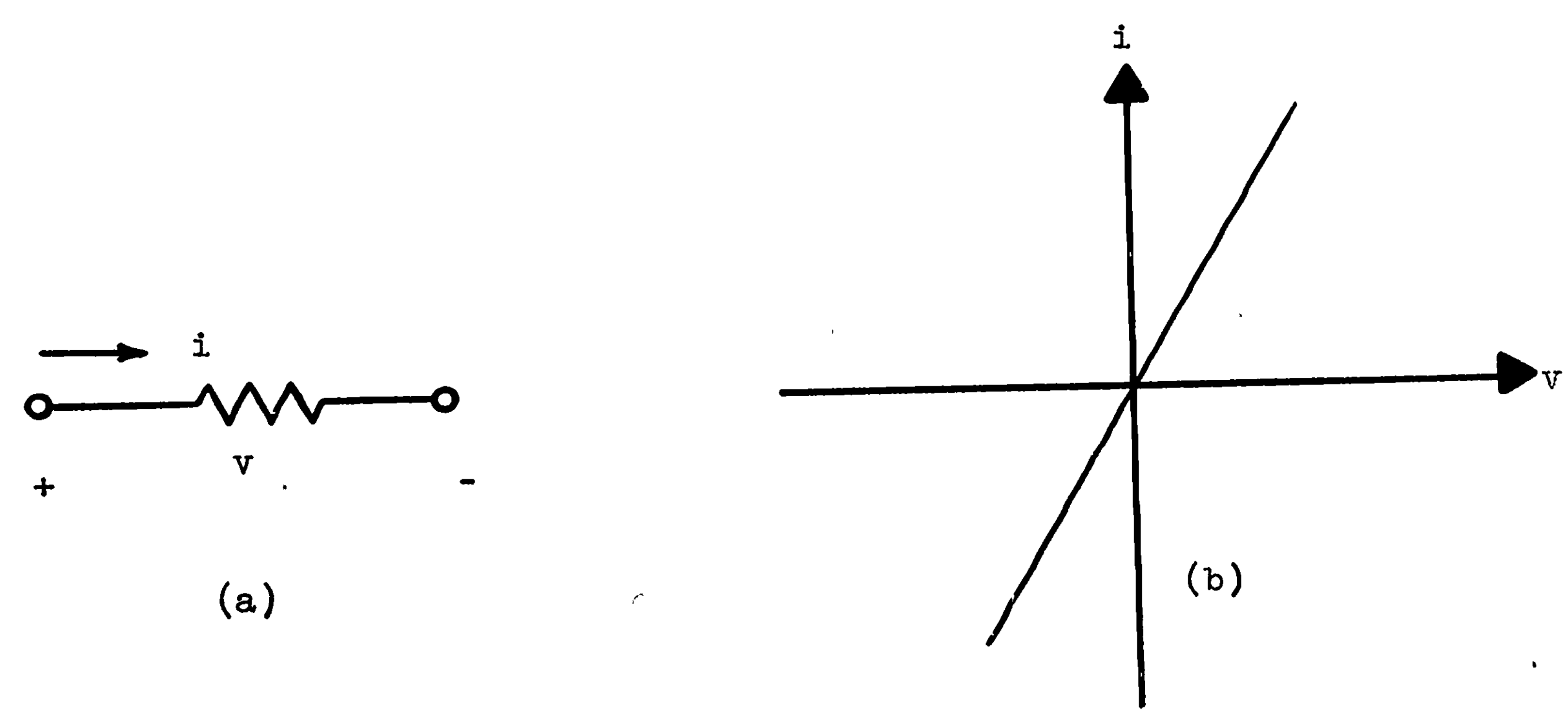


Fig. 1

DIODES

Section I

An ideal resistor is an hypothetical network element which is shown in symbolic form in Fig. 1a. The current is proportional to the voltage in this element as depicted by the straight line current-voltage curve in Fig. 1b.

Question: The resistance, R, is determined as:

(a) The slope of the current-voltage curve.

(b) The reciprocal of the slope of the current-voltage curve.

2

<u>Answer</u>: (b) The reciprocal of the slope of the current-voltage curve. (Note: the abscissa is voltage and the ordinate is current.)

Many electrical conductors, such as copper and aluminum, exhibit a behavior such that the voltage and current are proportional. But in order that the strict proportionality between voltage and current apply, it is usually necessary that the temperature of the conductor be held constant.

<u>Question</u>: A coil of copper wire is held at a constant temperature by immersing it in a deep ice water bath. A voltage of $\underline{V}$ volts results in a current of $\underline{I}$ amperes in the copper wire. Then the voltage is increased to $\underline{2V}$ volts. Determine the following ratios:

(a) the new current to the old;

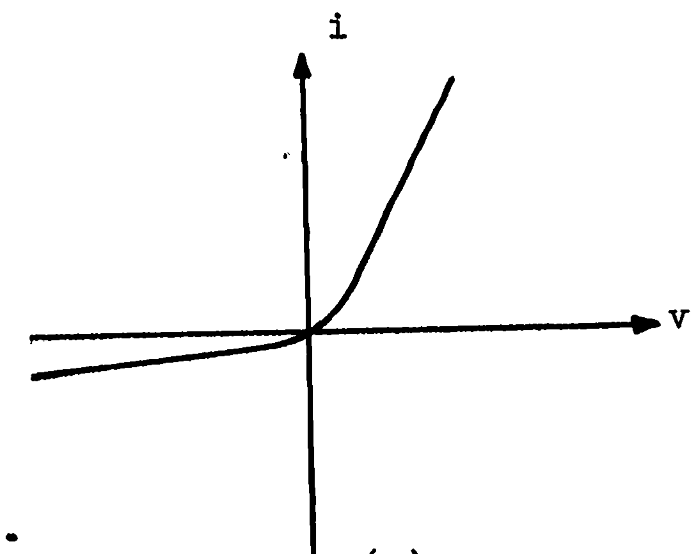
(b) the old power to the new.

4

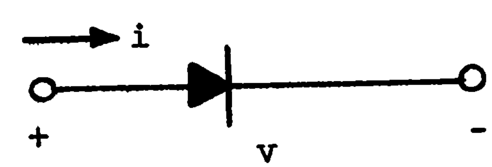
Answer: (a) 2

(b) 1/4

(Remember that power varies as the square of the current.)



(a)



(b)

Fig. 2

There are many important and useful devices in electrical engineering in which the current-voltage curve does <u>not</u> assume the form of a straight line through the origin. One such device is called a <u>diode</u>. In simple terms, a diode can be described as being a device requiring only a small voltage to produce current in one direction, the so-called <u>forward direction</u>. However, a much greater voltage is necessary to produce the same magnitude of current in the <u>reverse direction</u>. (In many instances, the voltage accompanying appreciable reverse current would be so high as to cause complete breakdown and destruction of the device.)

The above behavior is pictured graphically by the current-voltage curve for a typical diode in Fig. 2a. The schematic symbol of Fig. 2b will be used to represent an <u>actual</u> diode.

Note that the orientation of the arrowhead at the center of the symbol for an <u>actual</u> diode points in the <u>forward</u> direction.

<u>Question</u>: Compare the power dissipated in the above diode when $i = I$, with the power when $i = -I$ amperes. (Assume I to be some positive number.)

6

<u>Answer</u>: The power dissipated with the current in the reverse direction, $i = -I$, will be much greater than when the same magnitude of current is in the forward direction. This is a result of the much greater voltage that is necessary to sustain the current in the reverse direction over what is needed for the current in the forward direction.

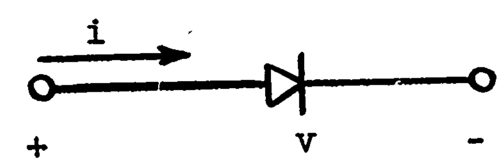


Fig. 3

We have seen that a diode tends to provide an easy path for current through itself in the forward direction while tending to prevent current in the reverse direction. This mode of operation leads us to the concept of an <u>ideal diode</u>. An ideal diode is an hypothetical network element having the following <u>three</u> properties:

(a) there is no reverse current;

(b) its voltage is zero when its current is forward (positive);

(c) its current is zero when its voltage is reverse (negative).

In order to distinguish an ideal diode from an actual diode, the slightly different symbol shown in Fig. 3 will be used.

See if you can write the three properties of an ideal diode in mathematical terms.

(a)

(b)

(c)

8

<u>Answer</u>: (a) $i \geq 0$

(b) $v = 0$ for $i > 0$

(c) $i = 0$ for $v < 0$

Since we shall be making continual reference to the plot of current versus voltage when discussing diodes, we shall adopt the convenient abbreviation, "i-v curve" for this plot. Likewise the expression "v-i curve" will serve to designate the plot of voltage against current.

Question: From the ideal diode definition in the previous frame, try to construct the i-v curve for an ideal diode.

10

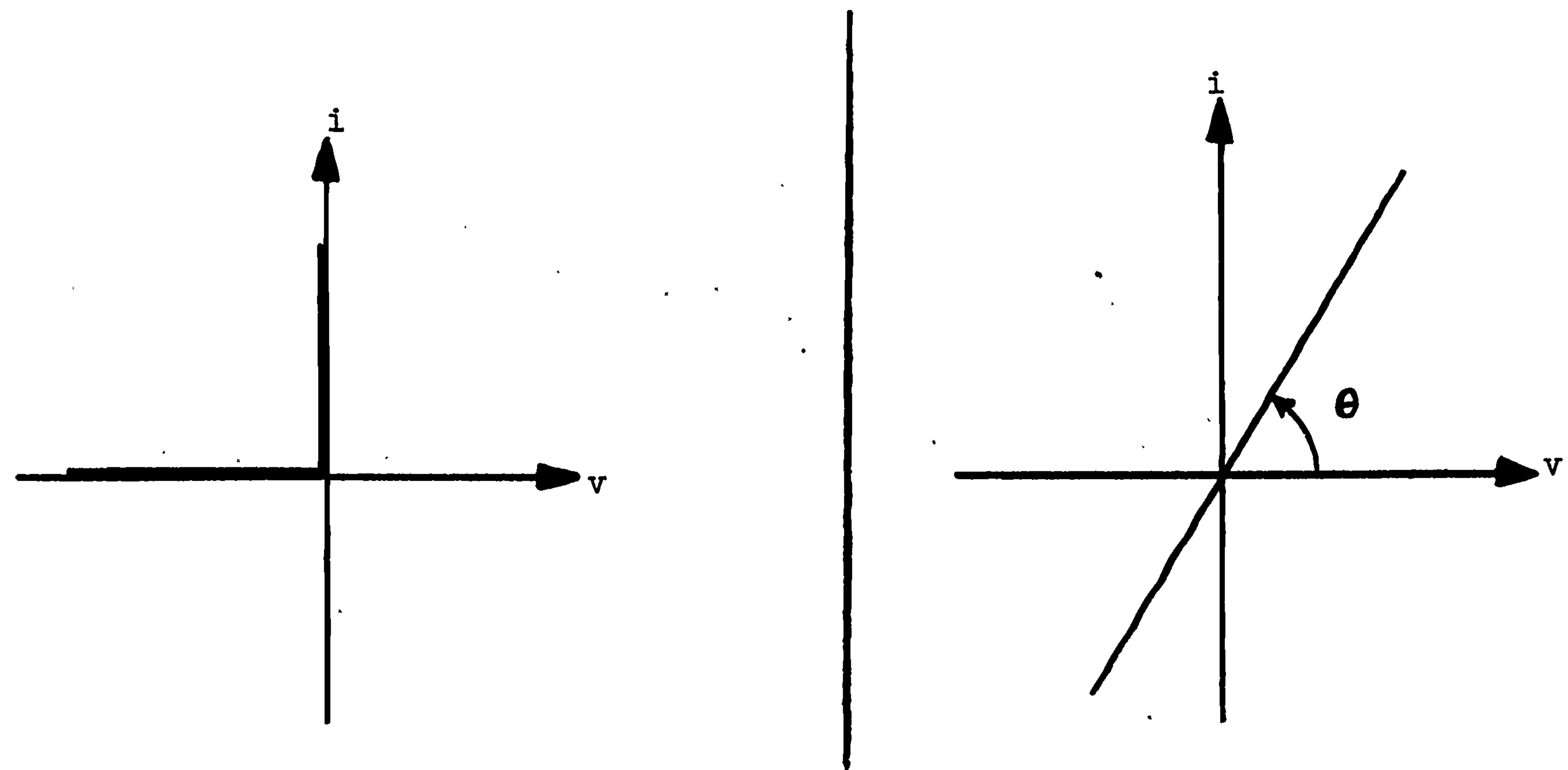


Fig. 4

When considering diodes there is a very useful concept known as the forward and reverse resistance of a diode. This concept may be introduced by consideration of the i-v characteristic of Fig. 4. This plot is indistinguishable from that of a resistor. Let us restrict our attention to this i-v curve for positive values of <u>v</u> <u>only</u>. Thus, when <u>v</u> is positive, so also is <u>i</u>. Moreover, the ratio of <u>v</u> to <u>i</u> is constant for a fixed value of θ.

<u>Question</u>: What must happen to θ if the first quadrant position of this i-v curve is to approach the same form as the vertical segment of the i-v curve for an ideal diode?

12

Answer: θ must approach 90°.

Continuing our discussion of the first quadrant segment of the i-v curve of Fig. 4, recall that the slope of this line and the resistance are related.

<u>Question</u>: What limiting value of resistance is associated with this line as θ approaches 90°?

14

<u>Answer</u>: 0 ohms.

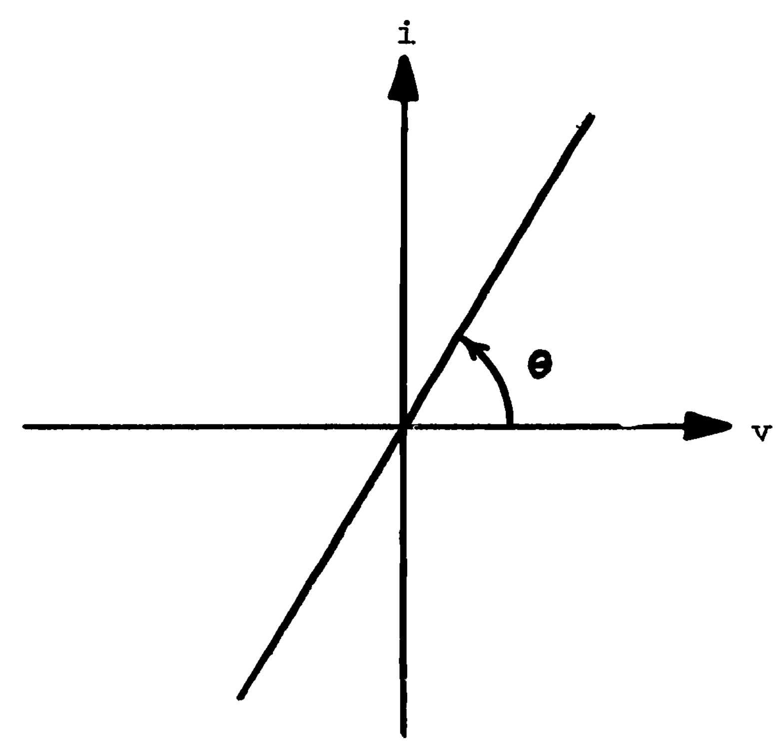


Fig. 4 (repeated)

In view of what you have just done, it should seem natural to say that <u>an ideal diode has zero resistance to forward current</u>.

We return to Fig. 4 and focus our attention on the third quadrant segment of this i-v curve as θ is made to approach zero. In this instance the segment is seen to become horizontal, taking on the same position as the horizontal segment of the ideal diode i-v curve.

<u>Question</u>: In view of the above interpretation, what can you say about the resistance of the ideal diode when the voltage is negative?

16

Answer: It will be infinite.

Later in this discussion we shall be talking about other than ideal diodes for which we will find the forward and reverse resistences to be finite, positive and non-zero.

Another description of an ideal diode is often usefully employed. An ideal diode is equivalent to a switch that is either <u>on</u> or <u>off</u>. When the diode is conducting, the switch is <u>on</u> and the <u>voltage is zero</u>.

Complete the following sentence:

When the diode is non-conducting, ____

________________________________.

18

<u>Answer</u>: the switch is <u>off</u> and the diode voltage is <u>negative (or zero)</u>. (or the current is zero.)

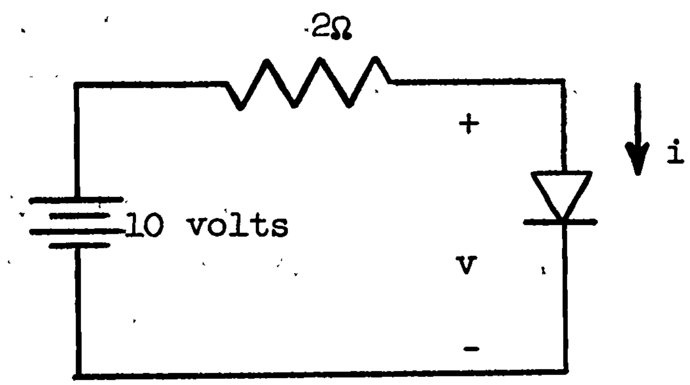
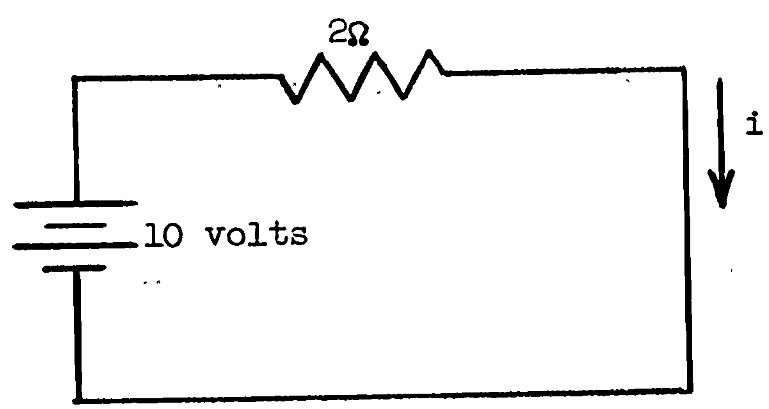


Fig. 5

When the diode current is positive, the diode voltage is zero, making it equivalent to a short circuit.

Question: Consider the circuit in Fig. 5. Redraw it with the diode replaced by its equivalent and calculate the diode current and the diode voltage.

20.



$$i = \frac{10}{2} = 5 \text{ amps.}$$

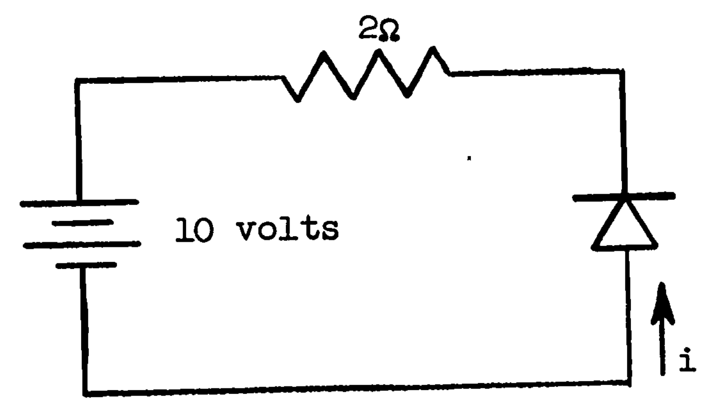
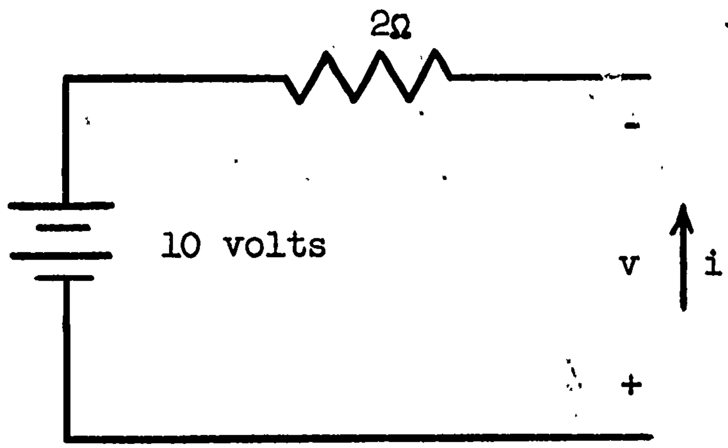


Fig. 6

When the diode voltage is negative, the diode current is zero and the diode is equivalent to an open circuit. Redraw the circuit in Fig. 6 having replaced the diode by its equivalent and calculate the diode current and the diode voltage.



$v = -10$ volts

$i = 0$ amps.

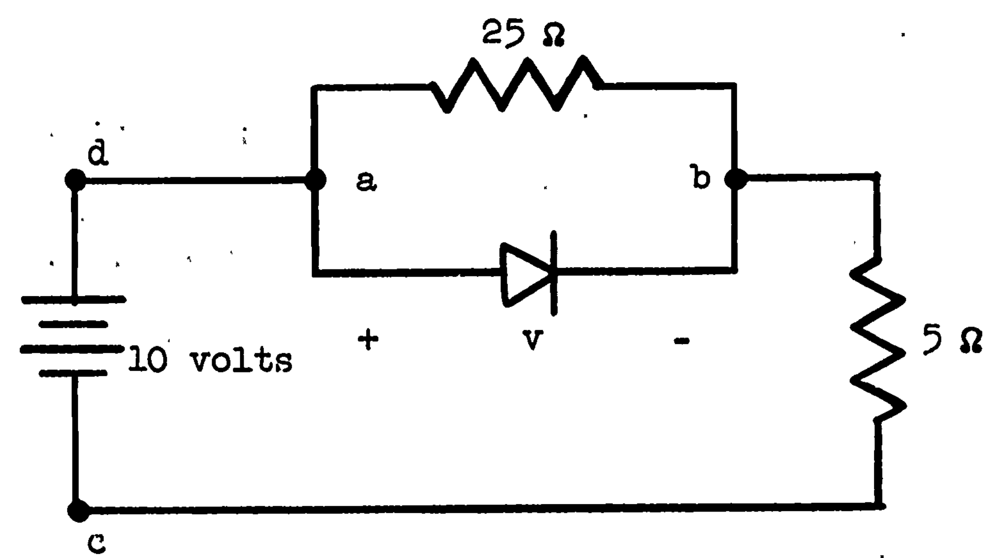


Fig. 7

In some networks it is possible to tell rather simply whether the ideal diode is in its open or closed condition. This will often be the case when there is only one source, whose voltage or current is constant, connected to a network of resistors and ideal diodes.

Consider the arrangement of elements as depicted in Fig. 7. What is the only possible direction for actual current in the 10 volt source?

24

<u>Answer</u>: from <u>c</u> to <u>d</u> through the source.
(Upward through the source.)

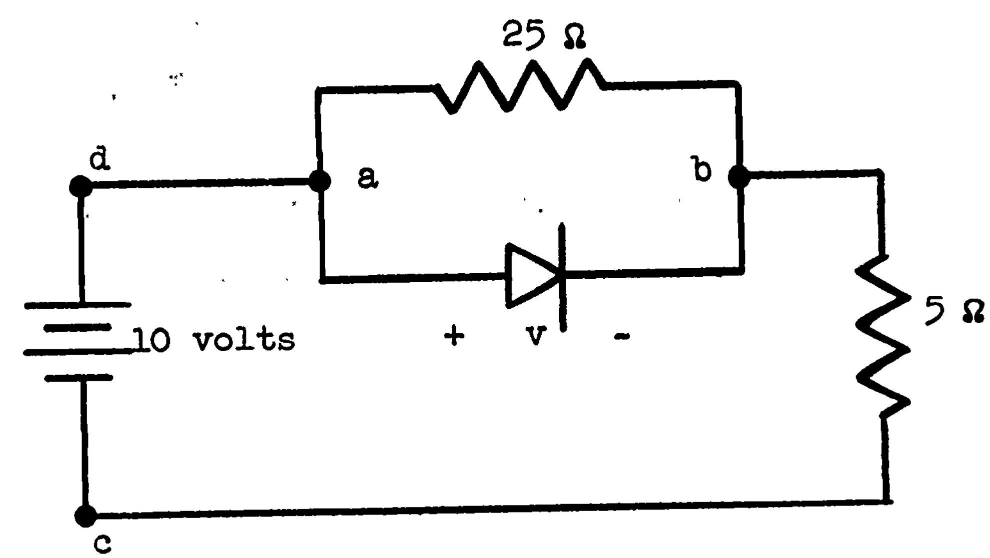


Fig. 7 (repeated)

With reference to the 25 ohm resistor in the network of Fig. 7, why is it impossible for the current to go from a to b through this resistor?

26

<u>Answer</u>: Since the diode and resistor are in parallel, current from <u>a</u> to <u>b</u> across the 25 ohm resistor would cause the diode voltage to be a positive quantity. This is not allowed by the diode.

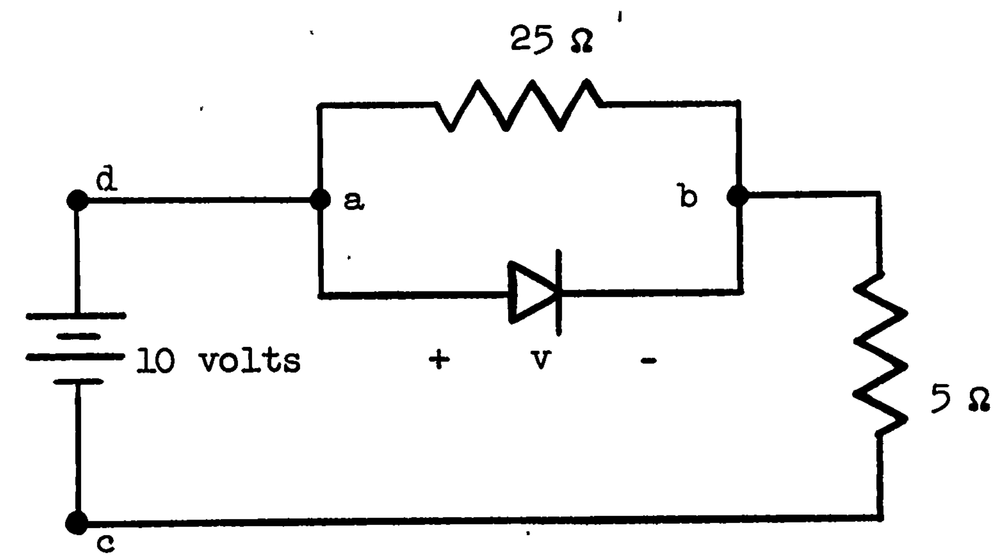


Fig. 1 (repeated)

Suppose that current in the 25 ohm resistor is in the direction from b to a. Then the diode will have a reverse voltage and hence zero current.

Question: Remembering that the only possible direction for current in the voltage source is upward, assuming the current in the 25 ohm resistor to be from b to a (which insures that the diode is an open circuit), how can the Kcl be satisfied at the junction a? What conclusion are we faced with?

28

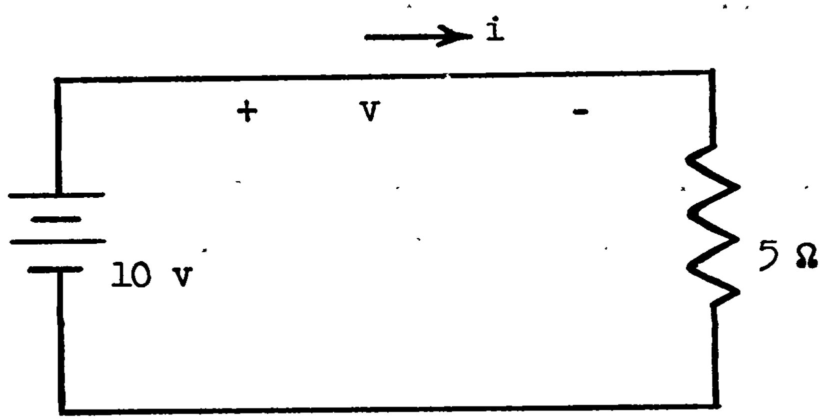
__Answer__: Under the conditions postulated, the Kcl cannot be satisfied at junction __a__. We can only conclude that current cannot exist in the 25 ohm resistor in any direction.

Since the 25 ohm resistor can carry no current in the circuit under consideration it must be equivalent to ____________________.

Redraw the circuit with both the diode and the 25 ohm resistor replaced by their respective equivalents, and determine the diode current and voltage.

30

<u>Answer</u>: an open circuit.



$$i = \frac{10}{5} = 2 \text{ amps.}$$

$$v = 10 - 5i = 0 \text{ volts}$$

(Answer all of the questions below, before checking your answers.)

Another feature of the ideal diode which deserves special attention is the dissipation of power.

1) The power absorbed by any electrical element having two terminals equals the produce of ________ and ________.
2) In the case of the ideal diode, current in the forward direction is always accompanied by zero voltage, which tells us that the power must be ________ for this case.
3) Similarly, when the diode voltage is negative, the current is ________.
4) Write a general statement telling the conditions under which the ideal diode dissipates powers.

32

Answer: 1) voltage and current

2) zero

3) zero

4) Ideal diode never dissipates power.

A brief and handy rule that accurately states the behavior of the ideal diode is easily remembered in the following form:

"Forward current means ______________ voltage while ______________ voltage means zero current."

34

__Answer:__ Forward current means __zero__ voltage and __reverse__ voltage means zero current.

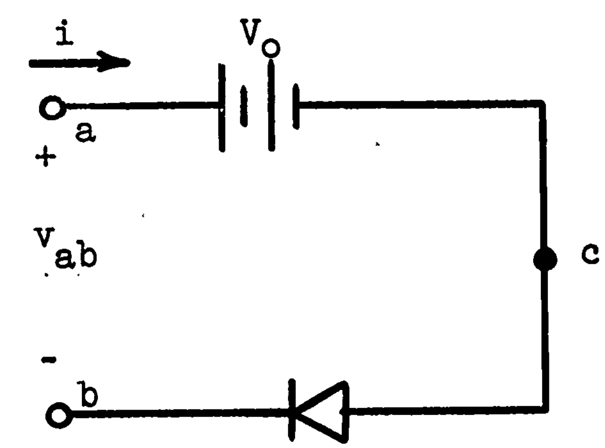


Fig. 8

Sometimes a voltage source is connected directly in series with an ideal diode as indicated in Fig. 3.

This combination can be viewed from the terminals a and b, and the network behavior considered in terms of the voltage and current associated with these terminals. The diode is often said to be <u>back biased</u> by the V_o volt battery in this arrangement because with no external voltage the diode voltage is negative.

Remember that there is only one current shared by the two elements and that the voltage, v_{ab}, equals the sum of the battery and diode voltages. Write the three fundamental properties of this two terminal element in analogy with those that were written for the ideal diode alone on page 7.

(a) ____________

(b) ____________

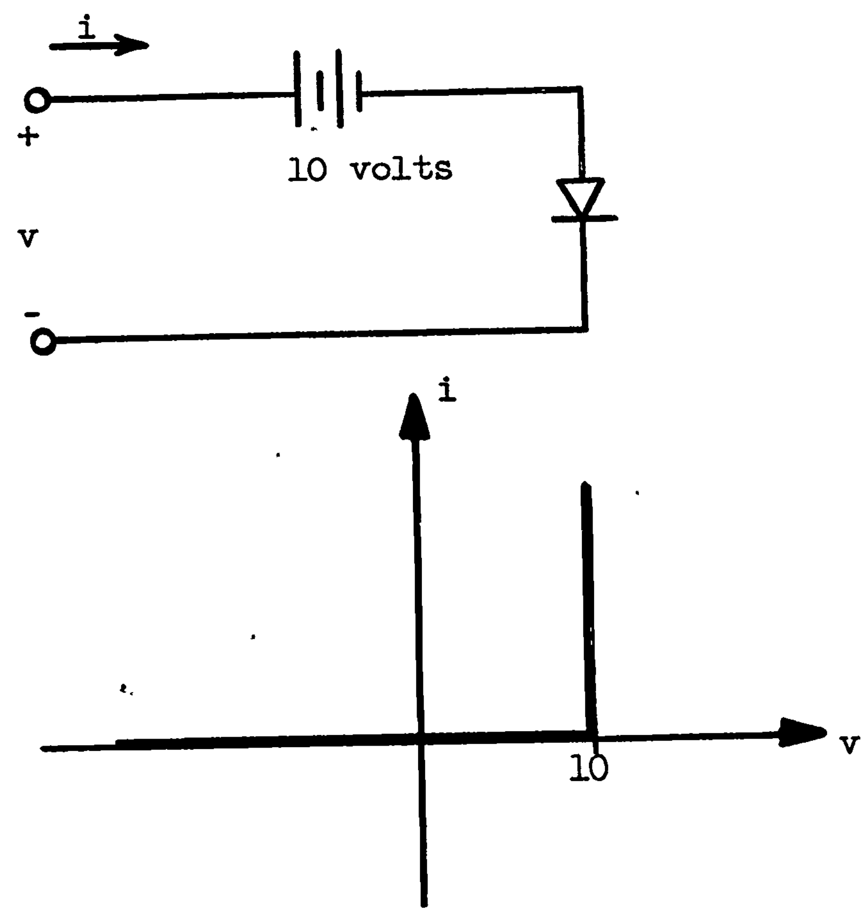
(c) ____________

Answer: (a) i must always be positive (or zero).

(b) $v_{ab} = E_o$ whenever i is positive.

(c) i is zero when v_{ab} is less than V_o. (This is true because i = 0 when the diode voltage is negative. By Kvl the diode voltage, $v = v_{ab} - V_o$).

Suppose that an ideal diode is back biased with a 10 volt battery. Draw the circuit and construct the i-v plot of this arrangement.



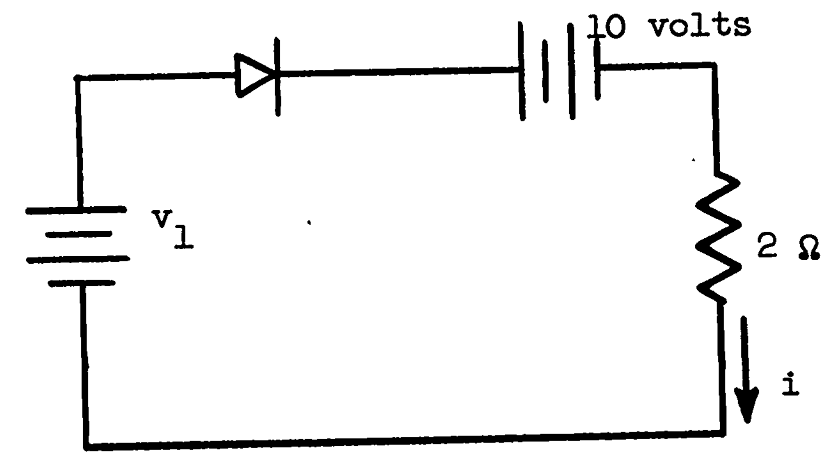


Fig. 9

We continue to examine the network response of the ideal diode using the network of Fig. 9. Here a diode is back biased by the 10v source. The current, $\underline{i}$, will be a function of the voltage $\underline{v_1}$ and a graphical plot of the current as a function of the voltage, $\underline{v_1}$, is the required result. It will prove instructive for us also to determine the diode voltage, $\underline{v}$, as a function of $\underline{v_1}$.

You can get things started by calculating:

(a) the current, $\underline{i}$, when $\underline{v_1} = 0$

(b) a literal expression for the diode voltage, $\underline{v}$, in terms of $\underline{i}$ and $\underline{v_1}$.

40

Answer: (a) $i = 0$ when $v_1 = 0$

(b) $v = v_1 - 2i - 10$

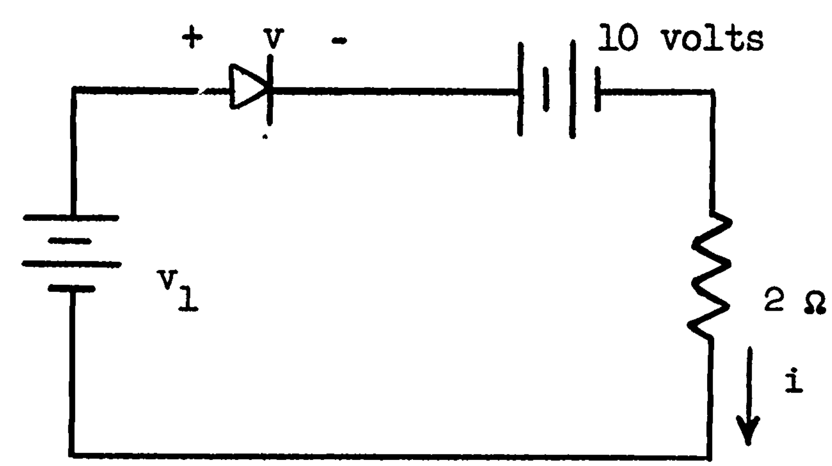


Fig. 9 (repeated)

To determine whether the diode is conducting or not, we need to examine its voltage. You have just calculated the diode voltage in quite general terms so let's use this expression. Since the diode has only two possible states (on or off), we can dispose of half our job by assuming the diode to be non-conducting.

Examine the expression for diode voltage, imposing the assumed restriction $i = 0$. Under this condition, what range of values of v_1 will insure the correctness of our assumption of no diode current?

42

<u>Answer</u>: $v = v_1 - 10 \leq 0$

$$\boxed{v_1 \leq 10}$$

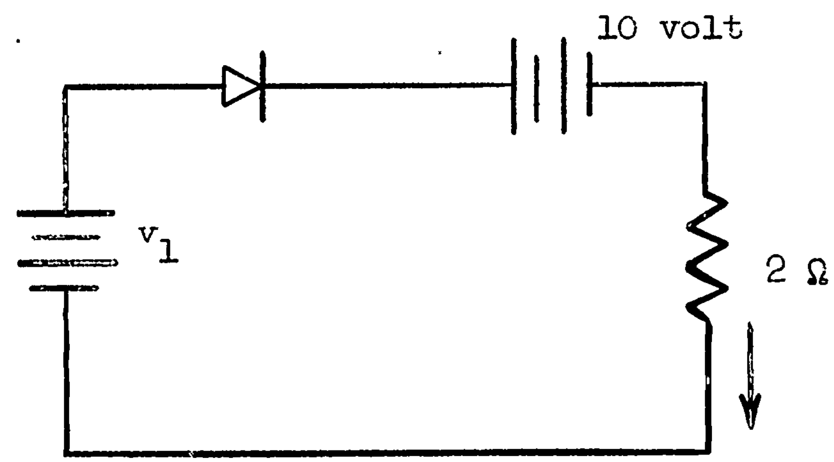
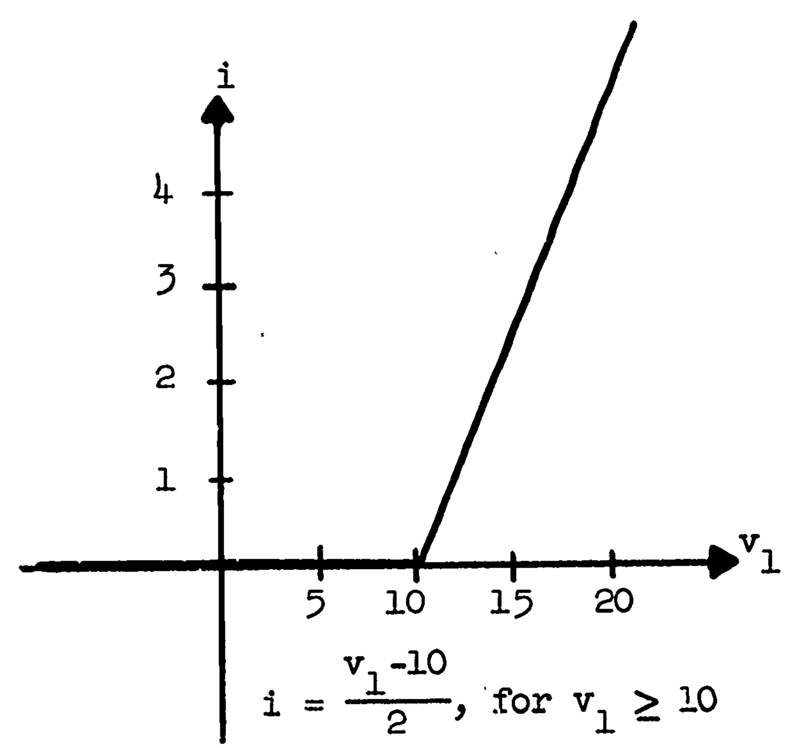


Fig. 9 (repeated)

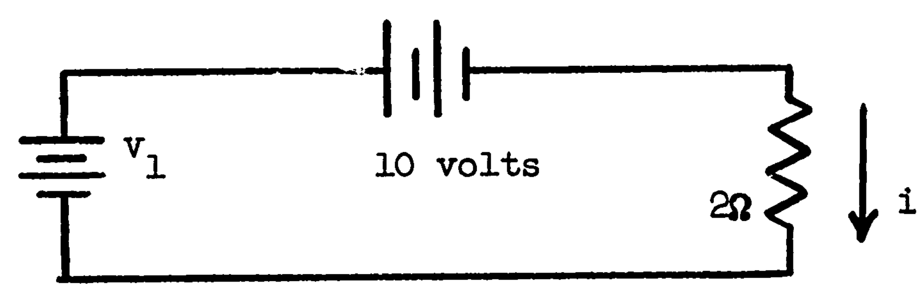
We have determined that when $\underline{v_1}$ is less than 10 volts the diode is non-conducting. It follows that when $\underline{v_1}$ exceeds 10 volts the diode will conduct.

Draw the equivalent circuit that applies to this situation for $v_1 \geq 10$ and calculate $\underline{i}$ as a function $\underline{v_1}$. Finally, plot $\underline{i}$ as a function of $\underline{v_1}$ for <u>all</u> values of $\underline{v_1}$.



$$i = \frac{v_1 - 10}{2}, \text{ for } v_1 \geq 10$$

$$i = 0, \text{ for } v_1 \leq 10$$



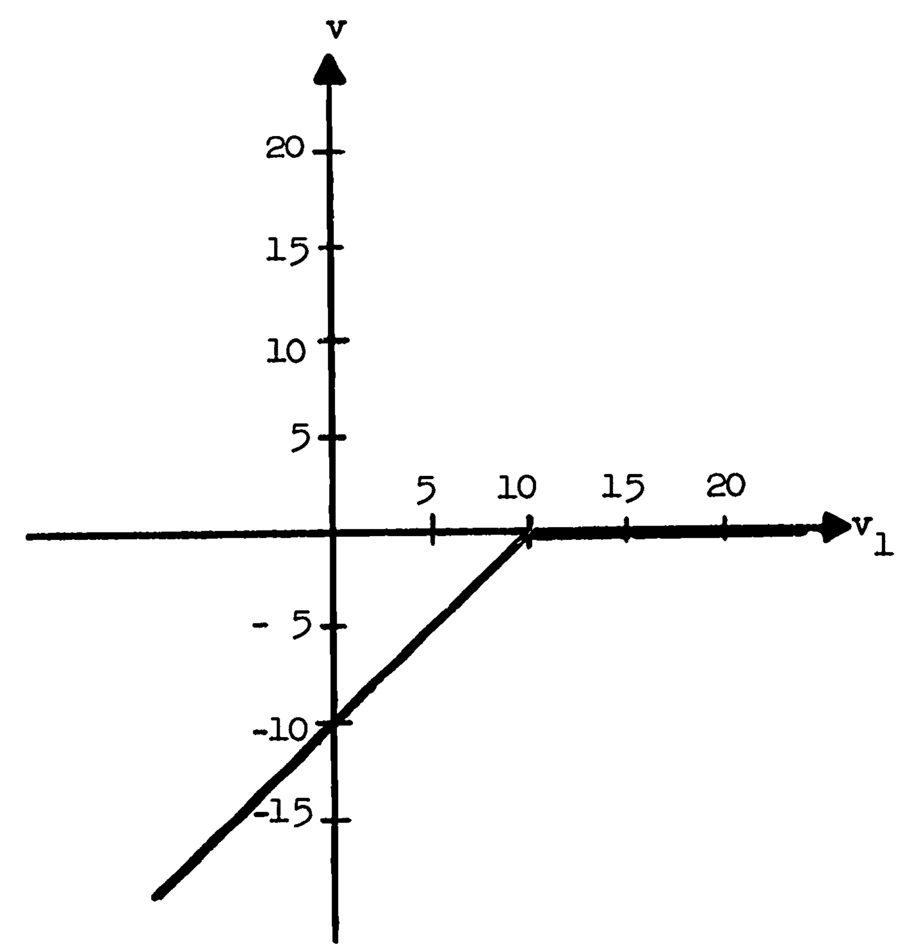


Fig. 10

As a finale to this little problem, let us now consider the diode voltage as a function of v_1. As derived earlier, $v = v_1 - 10 - 2i$ is the general equation for diode voltage. However, when the diode conducts, $(i \neq 0)$, we know that the diode voltage is zero. Thus the diode voltage is either zero or $v_1 - 10$. This result is indicated graphically in Fig. 10.

Using Fig. 10 and the plot of i versus v_1, as developed earlier, write a careful statement describing the behavior of this circuit and showing that the sample rule for ideal diodes (page 33) is not violated.

46

<u>Answer</u>: When $v_1 > 10$ the diode conducts requiring that its voltage be zero. This is the case in Fig. 10. When $v_1 < 10$ the diode voltage is negative requiring zero current which is the case in the plot of <u>i</u> versus <u>v_1</u>.

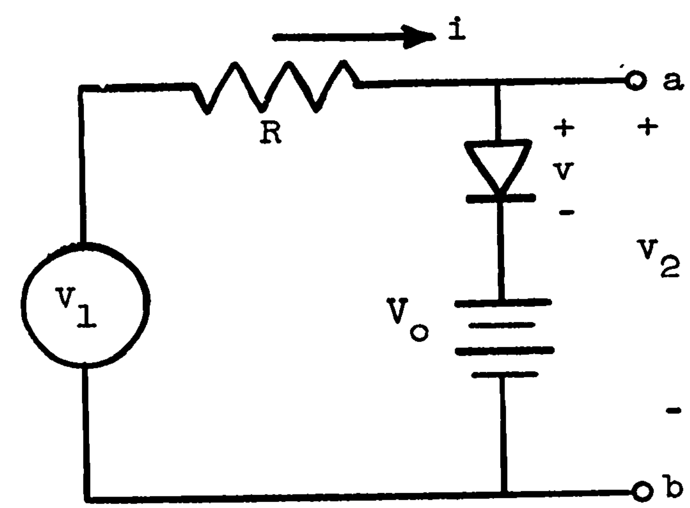


Fig. 11

Our next example, shown in Fig. 11, will be concerned with a circuit of some practical utility in which again there is a back biased diode.

The voltage v_1 varies with time. Our interest is in determining the variation of the output voltage v_2 with time. Let us first determine the dependence of v_2 on v_1; then when the variation of v_1 with time is given we can find the variation of v_2. (The output terminals, marked a and b in the figure, are to remain open circuited.) Our first objective is to find a plot v_2 against v_1.

Write an expression for v_2 in terms of the diode voltage v and the battery voltage V_o.

48

Answer: $v_2 = V_o + v$

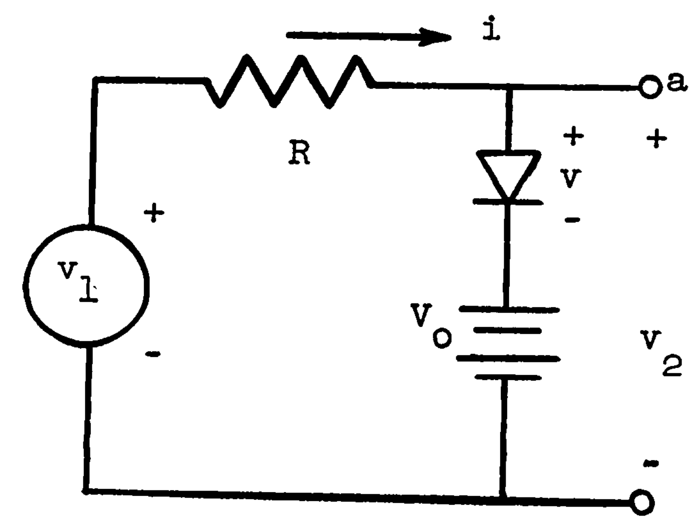


Fig. 11 (repeated)

In view of the permissible values of diode voltage, answer the following:

1) $\underline{v}$ is either ______________ or ______________.

2) What is maximum value of $v_{\underline{2}}$?

3) In what state does the maximum value of $v_{\underline{2}}$ place the diode?

50

<u>Answer</u>: (1) ... either <u>negative</u> or <u>zero</u>.

(2) V_o

(3) conducting

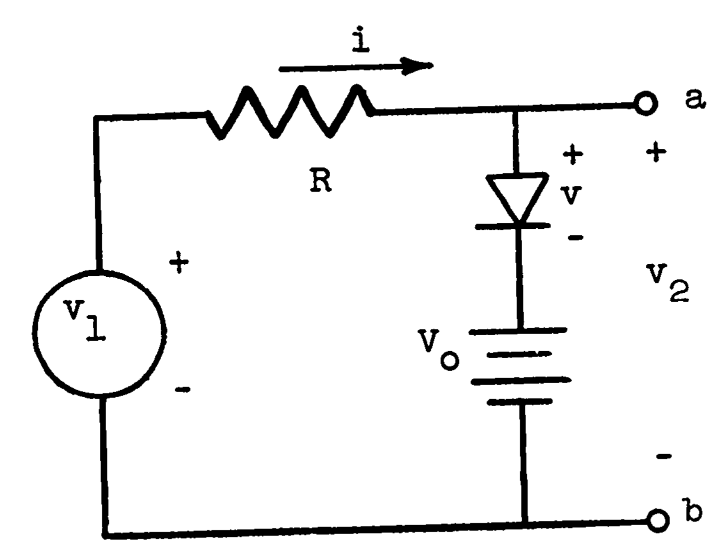
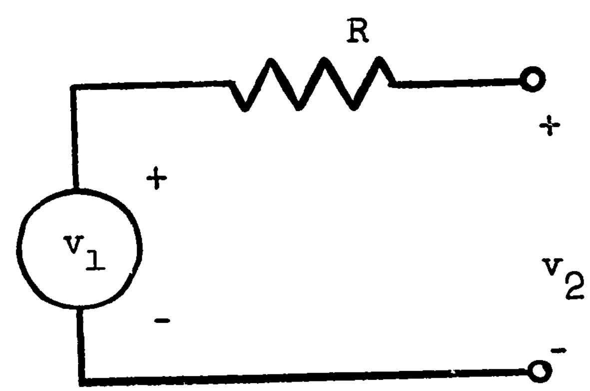


Fig. 11 (repeated)

Thus, when the diode is <u>off</u> the output voltage v_2 will be less than V_o. When the diode is <u>on</u>, the output voltage remains at V_o no matter what the value of v_1. But clearly, some value of v_1 will cause the diode to change state, to switch off.

When the diode is <u>off</u> replace it by an appropriate equivalent circuit in the diagram and find an expression for v_2.

52



$v_2 = v_1$

(since there is no current)

Thus, the output voltage $\underline{v_2}$ is equal to the input voltage $\underline{v_1}$ when the diode is off.

To summarize:

$v_2 = V_o$ (a constant) when the diode is on. Furthermore, this is the maximum value for $\underline{v_2}$.

$v_2 = v_1$ (a variable) when the diode is off.

The only problem remaining is to determine for what value of $\underline{v_1}$ the diode switches from off to on. You should do the following:

1) State the value of $\underline{v_1}$ at which the diode switches, and complete the following:

2) $v_2 = v_1$ when v_1 ____________,

3) $v_2 = V_o$ when v_1 ____________.

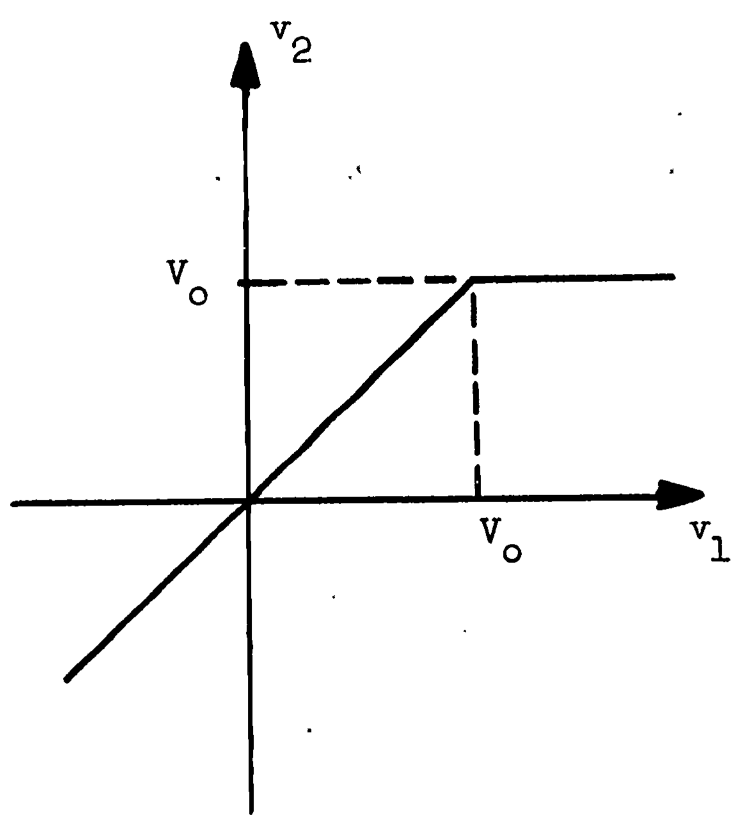
Answer: 1) Diode switches when $v_1 = V_o$.

2) $v_2 = v_1$ when v_1 is less than V_o.

3) $v_2 = V_o$ when v_1 is more than V_o.

It is now possible to plot $\underline{v_2}$ against $\underline{v_1}$. Make this plot and label it appropriately.

2



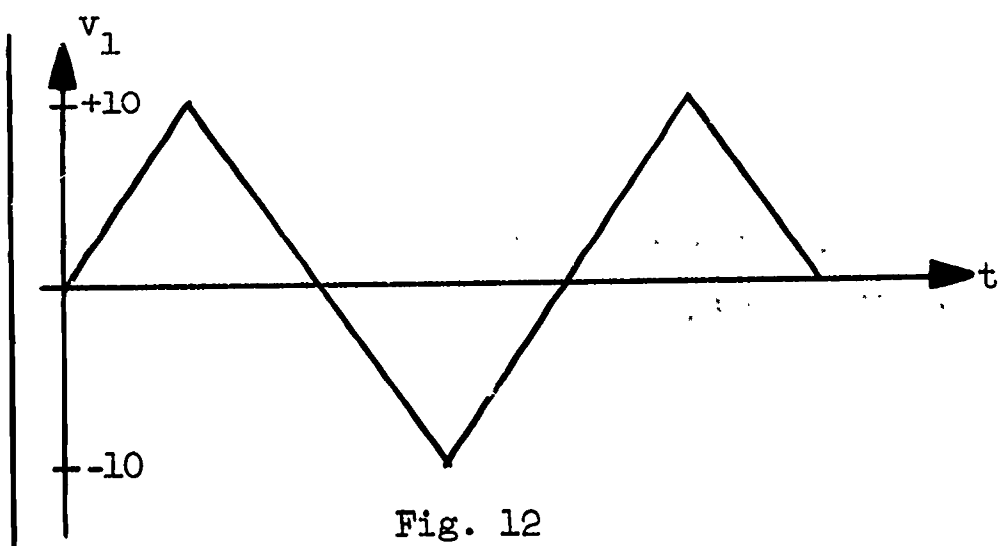


Fig. 12

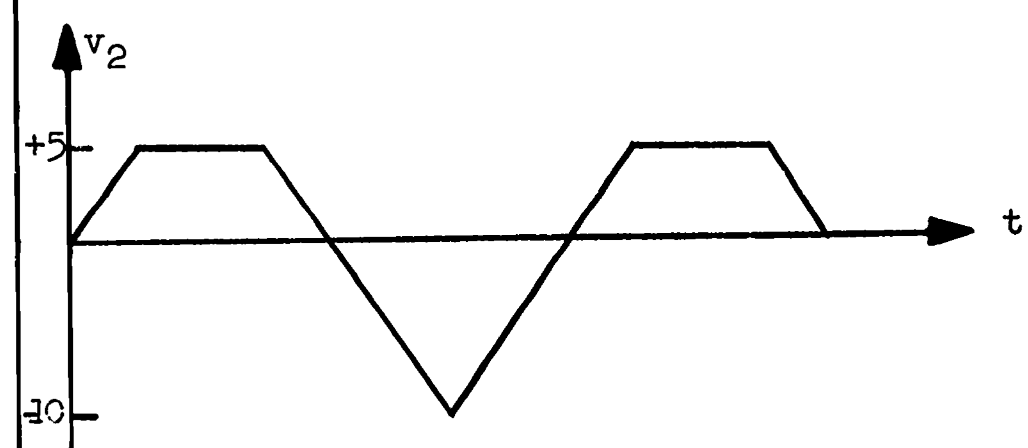


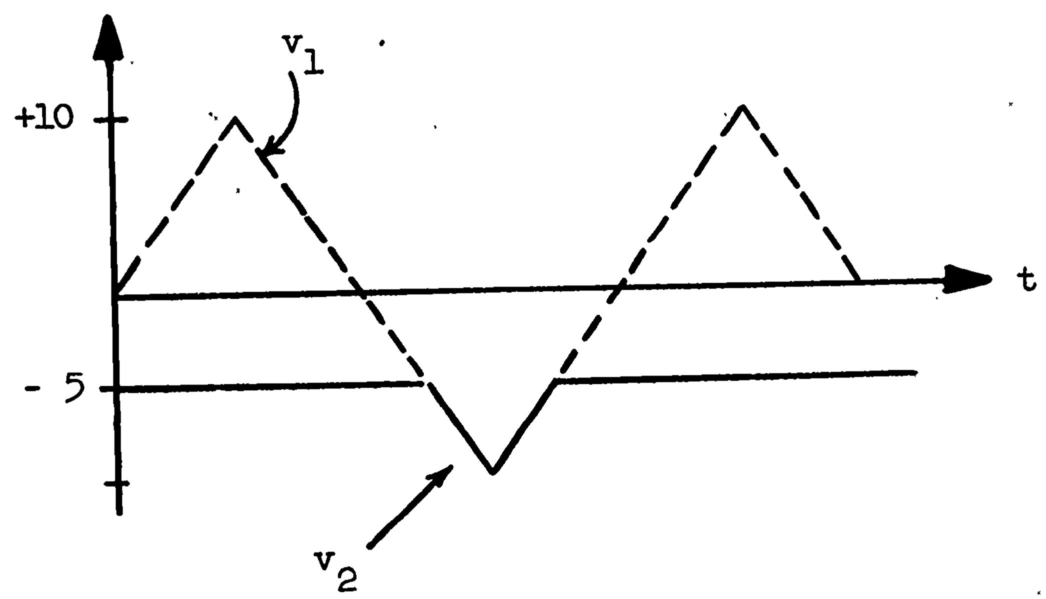
Fig. 13

From the plot of v_2 against v_1 we see that the output voltage v_2 is limited to those values of v_1 less than V_o. The circuit under discussion is accordingly called a limiter. In the present case only the positive values of the output voltage are limited.

Suppose v_1 has the time variation shown in Fig. 12.

It is desired to plot the time variation of v_2 for $V_o = 5$ volts. From the $v_2 - v_1$ plot we see that v_2 will duplicate v_1 whenever v_1 is less than 5 volts. When v_1 is greater than 5, v_2 will remain at 5. Hence the plot of v_2 will take the form of Fig. 13.

Plot v_2 against time for the same v_1, assuming $V_o = -5$. On the same diagram show the plot of v_1 dotted.



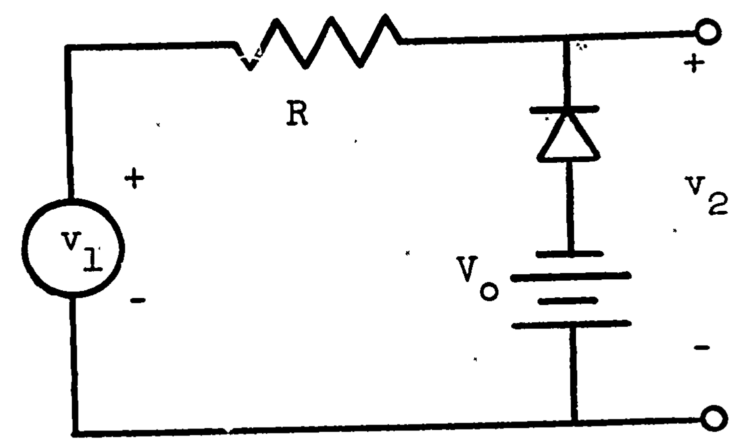


Fig. 14

In Fig. 14 is shown a slightly modified version of the previous circuit.

Describe in your own words how the behavior of this circuit compares with that of the former circuit, Fig. 11.

Answer: The behavior is very similar. However, this circuit will limit the negative excursions of $\underline{v_2}$ to values that are no more negative than $\underline{-V_o}$ volts. There will be no effect upon the positive values of $\underline{v_2}$.

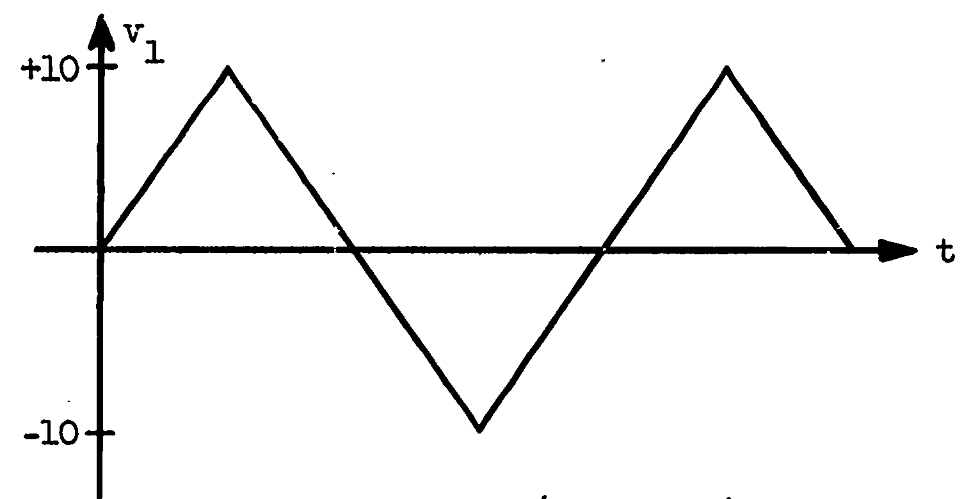
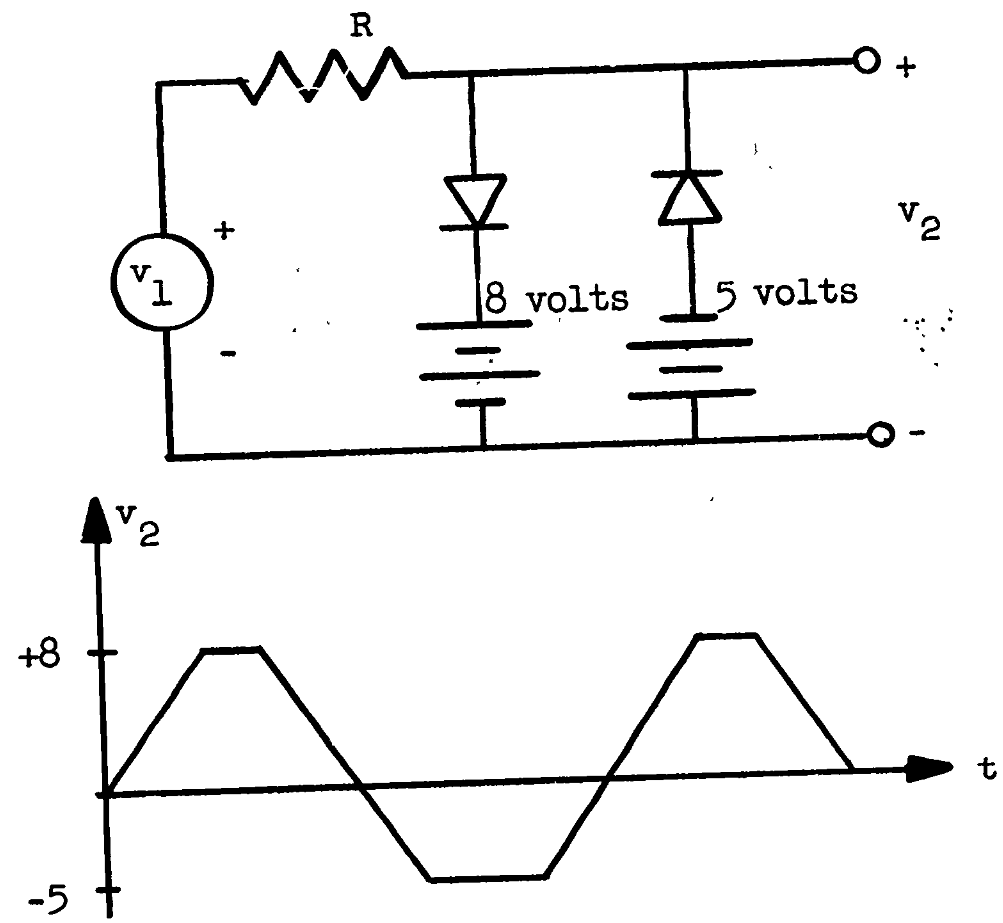


Fig. 12 (repeated)

There is a way of combining the two most recent circuits, that we have studied, into an arrangement that simultaneously limits both the positive and negative values of a voltage.

Try to design a circuit so that the positive amplitude is limited to 8 volts and the negative amplitude to -5 volts. Sketch the limited voltage if the source is that of Fig. 12.



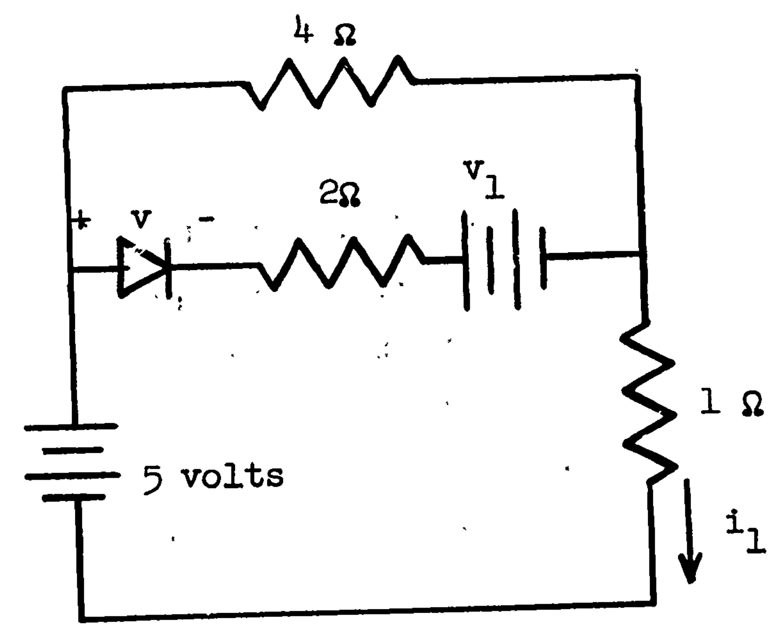


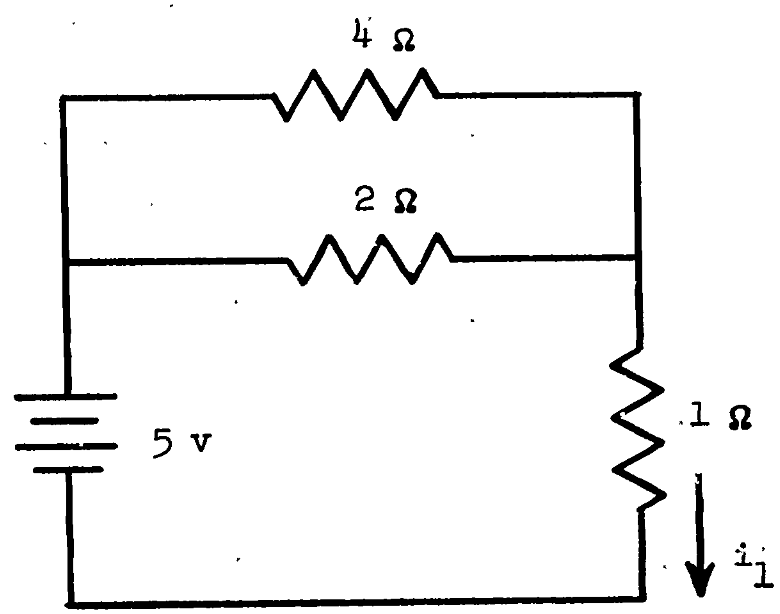
Fig. 15

Increasing the complexity somewhat, let us move on to the network of Fig. 15. The current, $\underline{i_1}$, will vary with the source voltage, $\underline{v_1}$, and a plot of this current with the source voltage is the desired relationship.

You might at first be tempted to throw up your hands at the seeming difficulty of this problem, but do not despair. You will see that a series of simple steps leads to the complete solution.

Our method of attack will be comprised of three steps. At first we shall assume the diode to be open and calculate the diode voltage for this case. Then we shall examine this expression, noting when the diode voltage is negative, for this is when the diode is actually open. Finally, the diode is assumed to be closed and $\underline{i_1}$ versus $\underline{v_1}$ determined for this case.

As a useful check on some of our later results, determine $\underline{i_1}$ in the <u>limiting case</u>, $\underline{v_1} = 0$. (It may prove helpful to redraw the circuit into simpler form.)



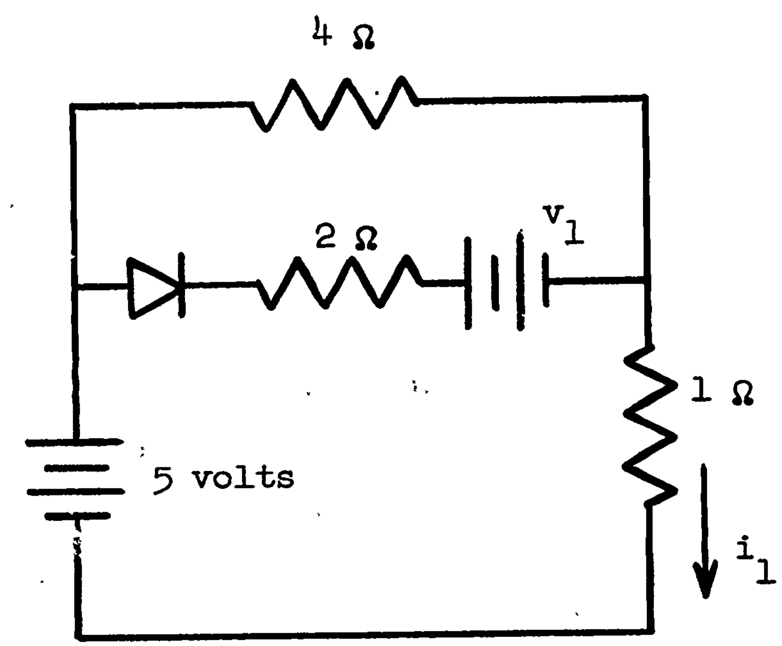


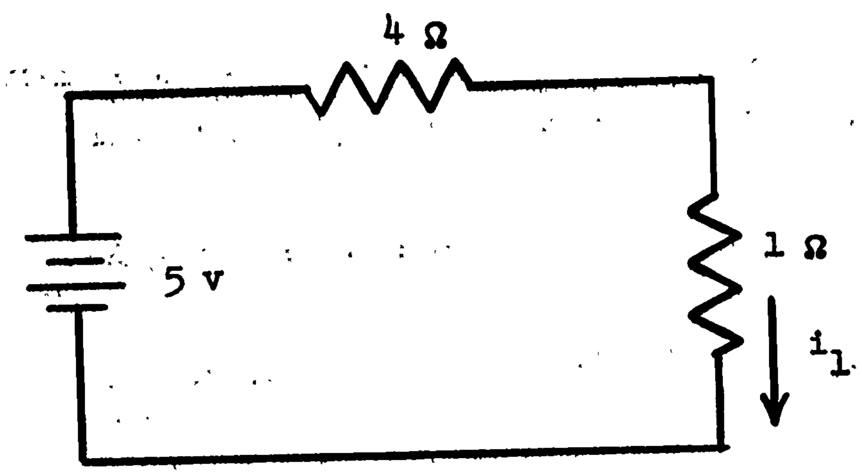
Fig. 15 (repeated)

$$i_1 = \frac{5}{\frac{4}{3} + 1} = \frac{15}{7} \text{ amps.}$$

Remember that the ideal diode is a <u>two</u> state device, equivalent to either a short circuit or an open circuit. To solve this problem completely both cases must be considered.

Inspection of the network indicates that with the diode open circuited, the simplest situation occurs.

Redraw the circuit into equivalent form for the case of the diode open and calculate $\underline{i_1}$.



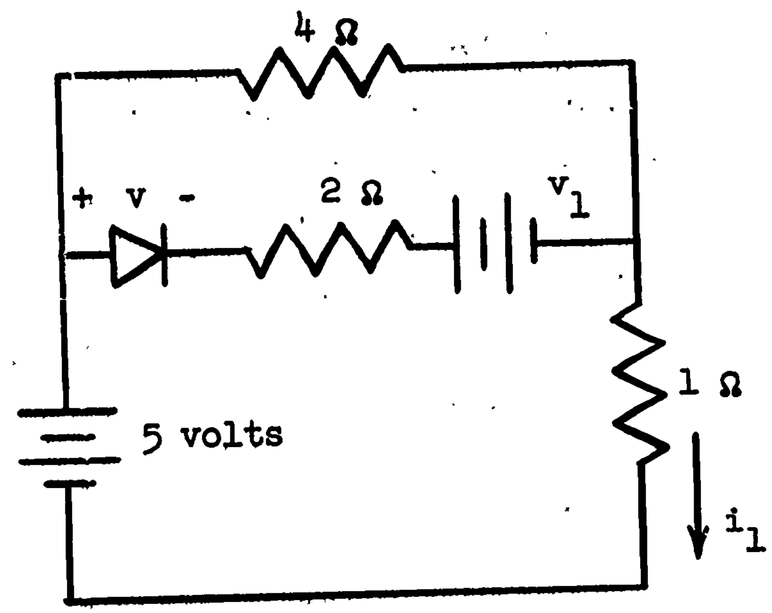
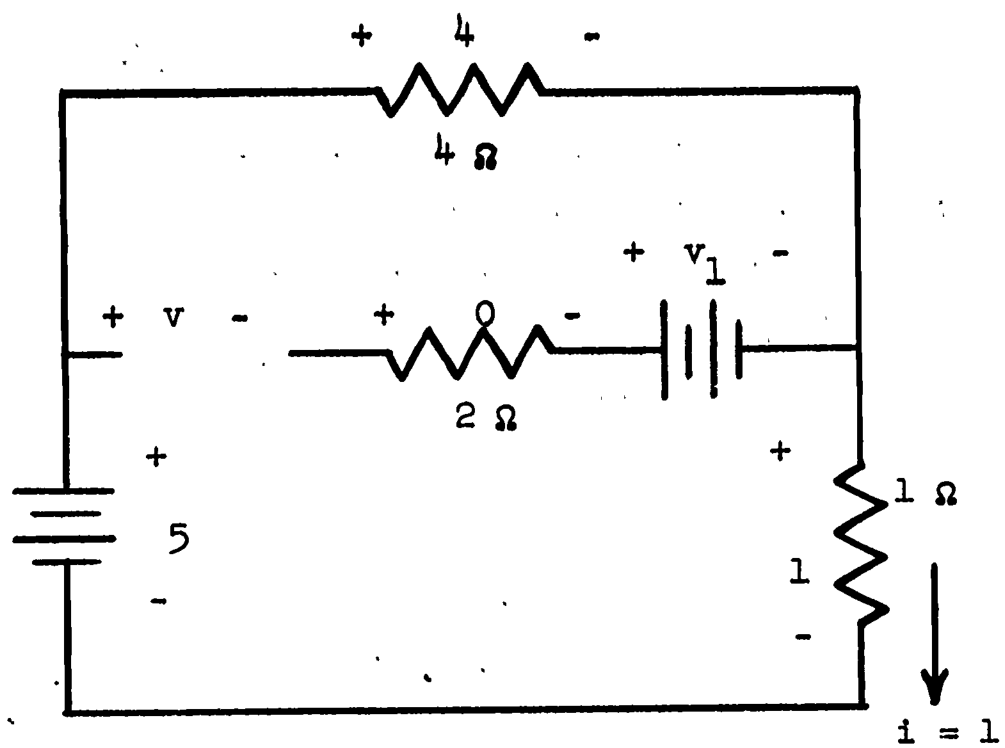


Fig. 15 (repeated)

The basic question, as always, is under what conditions will the diode be open (or closed)? We can begin to answer this question by assuming the diode to be open (this is the simpler case) and determining the diode voltage under this assumption. This you should do now. (May I suggest that you begin by drawing the appropriate circuit diagram with the voltage across each element clearly labeled?)

68



$v = 4 - v_1$

Although it may appear that we have not accomplished a great deal yet, perhaps it is well to summarize what we have learned at this point:

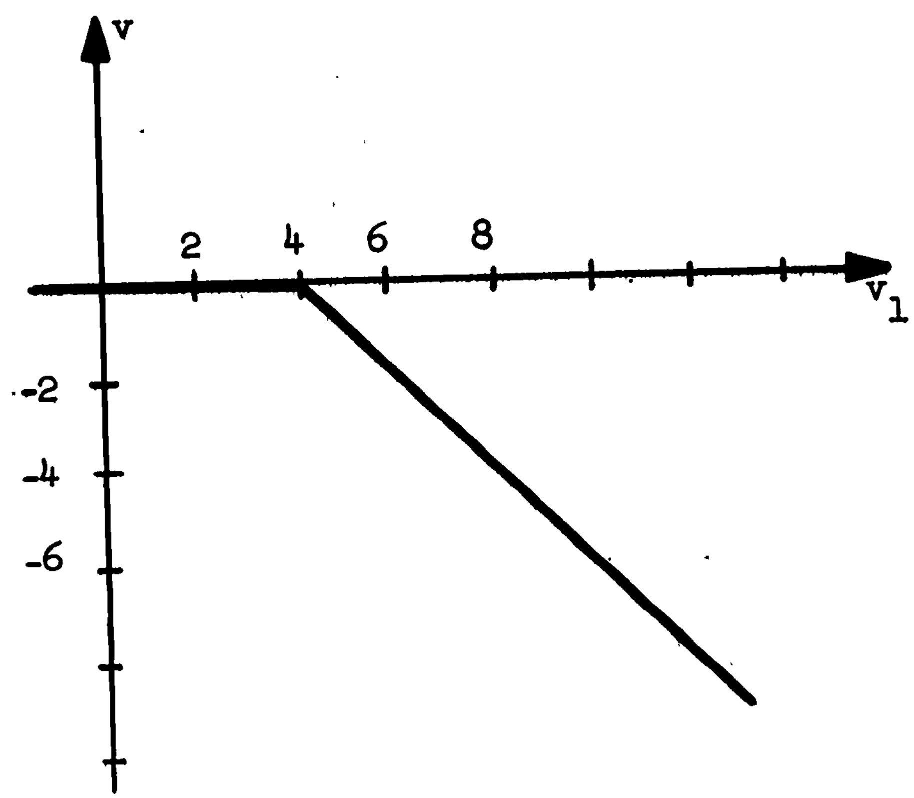
We know that, <u>when the diode is open</u>:

(a) $i_1 = 1$ amp.

(b) the diode voltage is $v = 4 - v_1$ volts.

It follows that when $4 - v_1$ is negative, the diode is open. The critical value for v_1, separating conduction from non-conduction, is therefore $v_1 = 4$ volts. Moreover, when $v_1 < 4$ the diode conducts and its voltage is zero.

There is now sufficient information to construct a plot of the diode voltage as a function of $\underline{v_1}$. That is your present task.



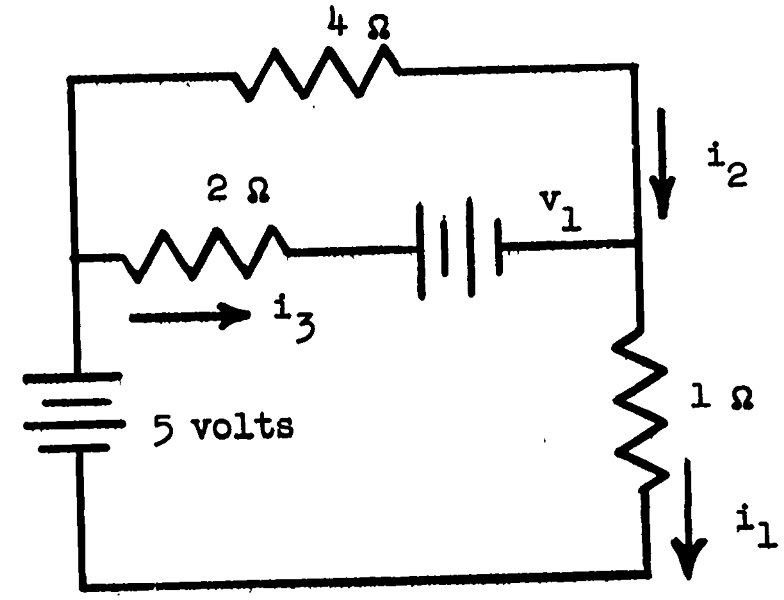


Fig. 16

To complete the solution of this problem we must now consider the situation for $v_1 < 4$. In this case the diode is a short circuit and the network simplifies to that of Fig. 16.

The desired current, i_1, is one of the currents in a two loop network. Among the variety of ways of determining i_1 we choose to impose Kvl and Kcl restrictions and solve for the current i_1. For this purpose, you are asked to:

(a) Express i_3 in terms of i_1 and i_2.

(b) Write the Kvl equations that result from summing voltages around the two meshes. Simplify by eliminating i_3 and rearranging these equations so that i_1 and i_2 terms appear on the left side and all other terms on the right side.

72

<u>Answer</u>: (a) $i_3 = i_1 - i_2$

(b) $2i_1 - 6i_2 = -v_1$

$3i_1 - 2i_2 = 5 - v_1$

The final step in the solution of this problem is the solving of these equations for i in terms of v_1. When this is accomplished there will be enough information to plot i against v_1 for all values of v_1.

Solve the previous equations for the desired i as a function of v_1. Also verify the correctness of your answer by setting $v_1 = 0$, and comparing the result with your previous result that $i_1 = \frac{15}{7}$ when $v_1 = 0$.

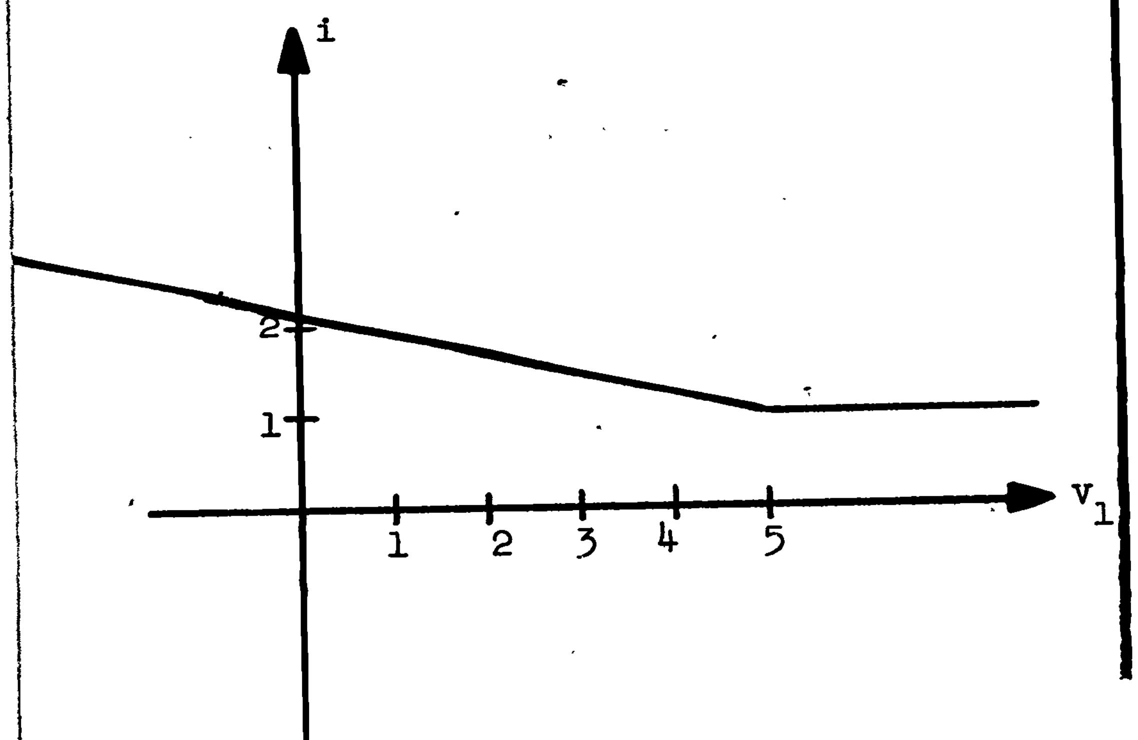
74

Answer: $i = \dfrac{15 - 2v_1}{7}$ for $v_1 < 4$

When $v_1 = 0$, $i = \frac{15}{7}$ which checks the previous result.

All of the required information is at hand for the construction of a plot of $\underline{i_1}$ against $\underline{v_1}$. Thus we know that $\underline{i_1} = 1$ for $v_1 > 4$ and $\underline{i_1} = \frac{15-2v_1}{7}$ for $\underline{v_1} \leq 4$. Construct the desired plot.

76



Summary

Fill in all of these statements before looking at answers.

1. The ideal diode is a switch-like element having exactly ______ modes of behavior.
2. As a switch it is either fully _____ or completely ______.
3. When fully on the ________ is zero, and when completely off the current is ___________.
4. There is never any current in the ____________ direction nor any ____________ in the forward direction.
5. The forward and reverse resistances of an ideal diode are respectively, ___________ and ______________.

6. Whether the ideal diode is actually in one or the other of the two possible states depends upon conditions in the circuit to which it is connected. Thus:

   a) If the circuit causes the diode voltage to be negative, the current will be __________, and the diode is equivalent to __________.

   b) If the circuit causes the diode current to be positive, the __________ will be zero and the diode is equivalent to __________.

7. A fruitful approach to the analysis of a network containing a diode involves the following three steps:

   a) Assume the diode to be open and calculate the desired quantity.

   b) Determine the conditions under which the above assumption is valid by ______________________________.

   c) Calculate the desired quantity when the diode is closed.

<u>Answers:</u>

1. <u>two</u> modes of behavior.
2. <u>on</u> or completely <u>off</u>.
3. <u>voltage</u> is zero ... current is <u>zero</u>.
4. in the <u>reverse</u> direction nor any <u>voltage</u> in the forward direction.
5. <u>zero</u> and <u>infinite</u>.
6. a) ... the current will be <u>zero</u> and the diode is equivalent to <u>an open circuit</u>.

   b) ... the <u>voltage</u> will be zero and the diode is equivalent to <u>a short circuit</u>.
7. b) examining the diode voltage under the above open circuit conditions. When this voltage is negative, the diode is indeed an open circuit. If the voltage tends to be positive the diode will become a short circuit.

DIODES AND DIODE CIRCUITS

Section II

In the preceding section a hypothetical device, the ideal diode, was introduced as a model of a physical device. This model has a behavior which is a first-order approximation of the behavior of an actual diode. It accounts for the major effects of easy forward current and difficult reverse current. In fact, the ideal diode makes forward current flow too easy and reverse current impossible.

The ideal diode calls for _____ forward resistance and __________ reverse resistance.

82

Answer: zero forward resistance

infinite reverse resistance

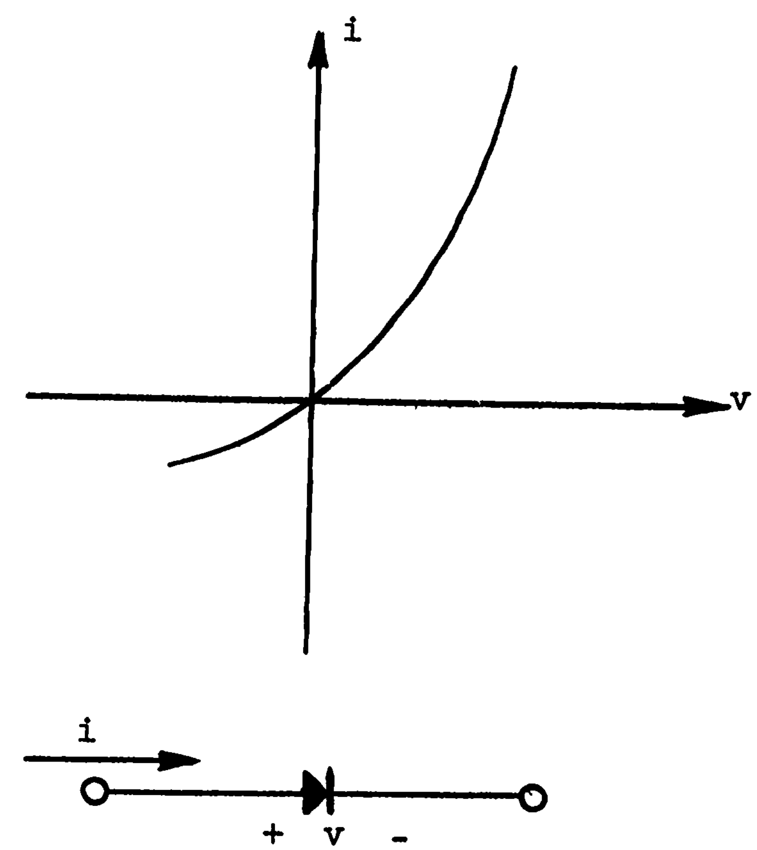


Figure 17

A typical i-v curve of a physical diode is shown in Fig. 17. The curve lies close to the positive current and negative voltage axes, but it is not coincident with them. Furthermore, it is not a straight line but is ______ ______.

84

<u>Answer</u>: curved (nonlinear)

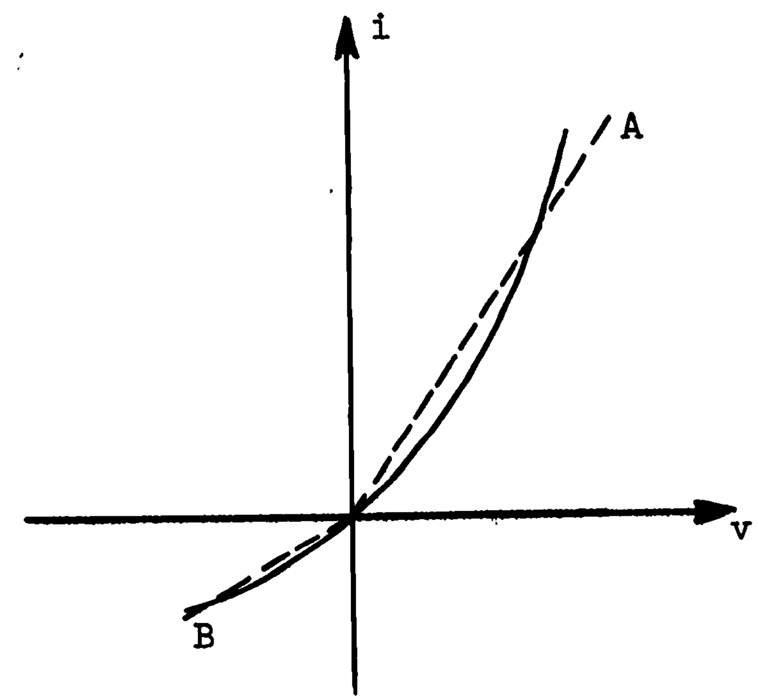


Figure 18

The notion of forward and reverse resistance was introduced as the inverse slope of the i-v curves, evaluated in the first and third quadrants, respectively. Since the slope of the i-v curve of Fig. 17 is not constant, even when we confine ourselves to either the forward or reverse region, then a unique forward or reverse resistance does not exist. This is most unfortunate because many simple and useful techniques are available when the i-v curve is composed of straight-line segments. For this reason, straight lines can sometimes be used to approximate the i-v curve as indicated by the dashed lines marked A and B in Fig. 18.

A device, having straight segments for its i-v curve as indicated by the lines A and B in Fig. 18, has a behavior in each region like that of a resistor. State the values of the forward resistance R_f and the reverse resistance R_r as properties of the lines A and B.

<u>Answer</u>: Forward resistance is the reciprocal of the slope of the line A. Reverse resistance is the reciprocal of the slope of the line B.

The dashed-line characteristic of Fig. 18 is not a single, but rather two straight lines, one for each portion or piece of the entire voltage range. This approximation is, therefore, called the <u>piecewise linear approximation</u> of the i-v curve.

The straight lines are drawn in such a way that they come "closest" to the actual curve. What it means to be <u>closest</u> depends upon the range of voltage or current over which the above ________ __________ approximation is to be applicable.

88

<u>Answer</u>: <u>piecewise linear</u> approximation

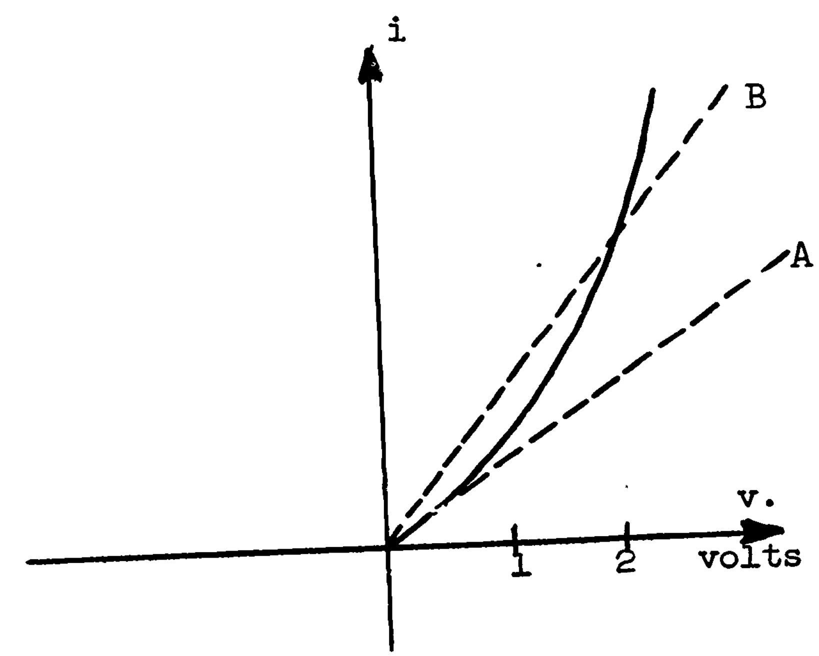


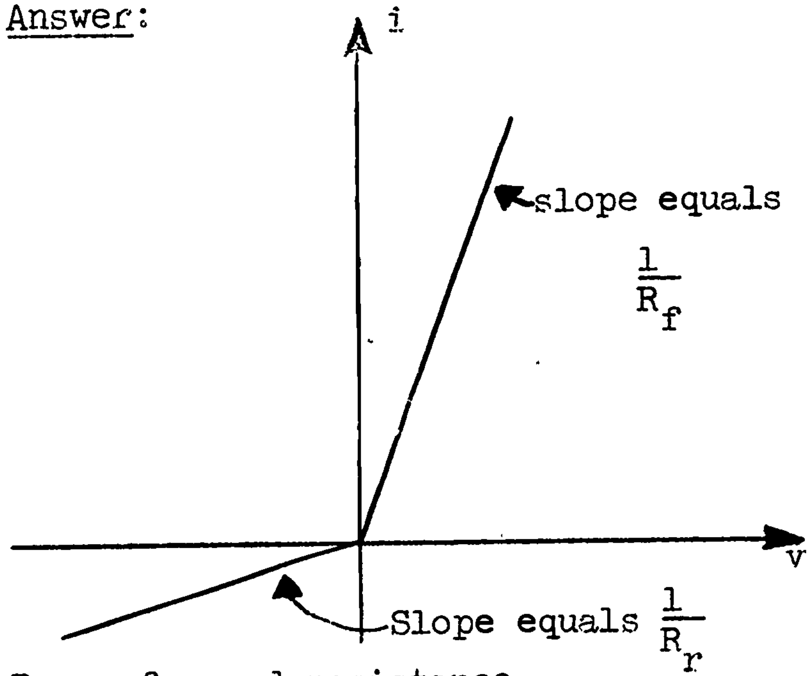
Figure 19

Consider, for example, the forward portion of a diode i-v curve drawn in Fig. 19. Suppose the voltages we expect across the diode do not exceed 1 volt, and we are interested in a piecewise linear approximation over this range, 0 to 1 volt. The line labeled A would be suitable. On the other hand, if the region of interest extended over the range 0 to 2 volts, the line marked A would lead to large errors near the 2-volt point. The second line, marked B, yields a much better approximation over the range from 0 to 2 volts.

A hypothetical element having an i-v curve in the form of two straight-line segments, one for the forward region, and one for the reverse region, is called a piecewise linear model diode, or simply a model diode, for brevity.

Draw a typical i-v curve for a model diode and label its pertinent properties.

<u>Answer</u>:



R_f -- forward resistance

R_r -- reverse resistance

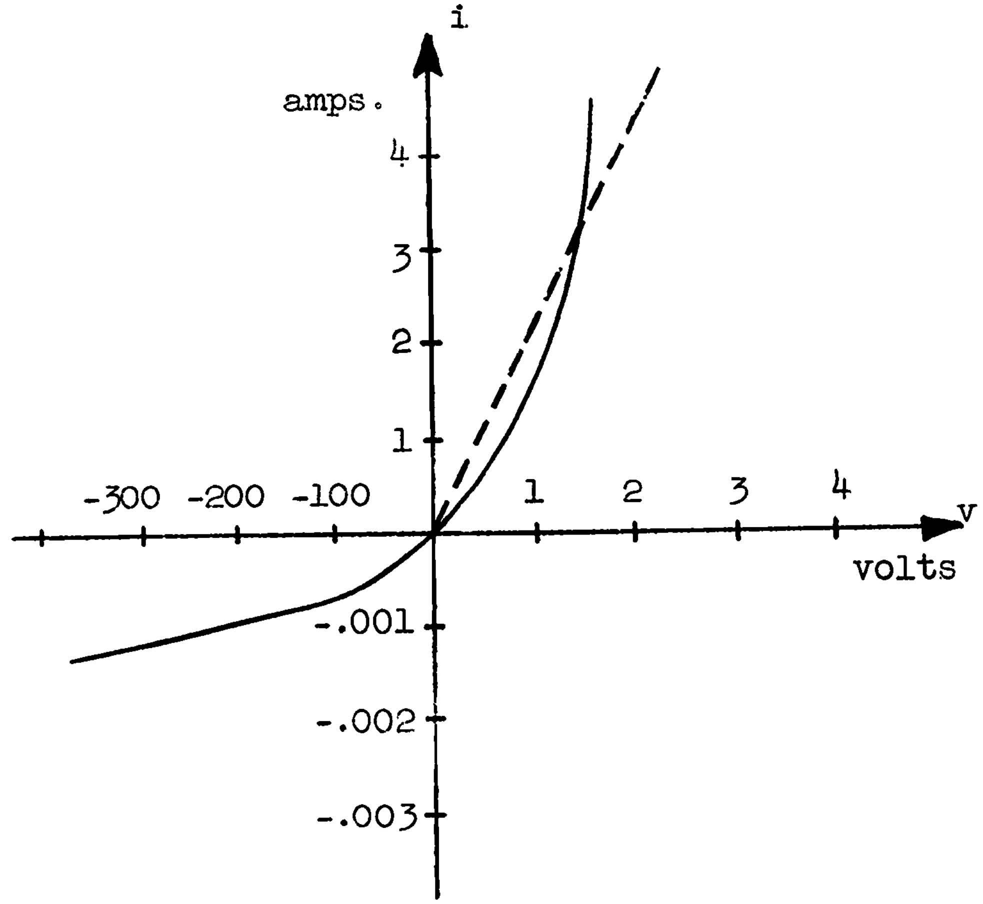


Figure 20

Figure 20 shows the exact i-v curve of a diode, drawn to scale. Note that the scale of the negative current axis is different from that of the positive current axis. Similarly, the negative voltage axis has a different scale from the positive voltage axis.

A straight-line segment, shown in dotted form, is chosen to approximate the first quadrant behavior of the exact diode curve. The slope of this line is 2.2 amps./volts. Therefore, the piecewise linear diode has a forward resistance of 0.45 ohms.

Using a clear plastic straightedge, construct your best choice of straight line to approximate the entire third quadrant segment of the i-v characteristic. Determine the reverse resistance of the model diode corresponding to your choice of straight line.

<u>Answer</u>: The answer to this questions will vary with the choice of approximating line. One choice yields a reverse resistance of 230 k ohms. Your answer should be within 10-15% of this one.

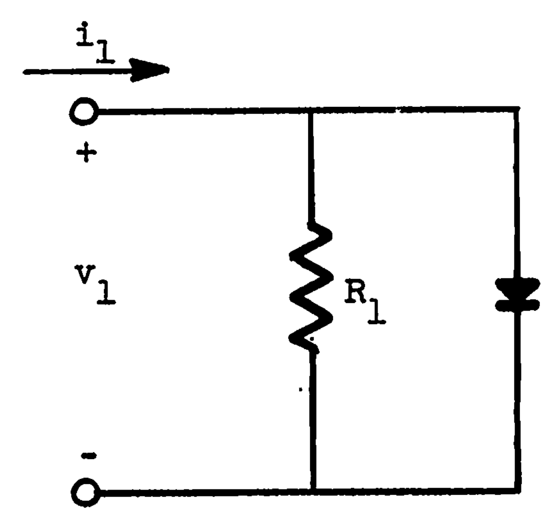


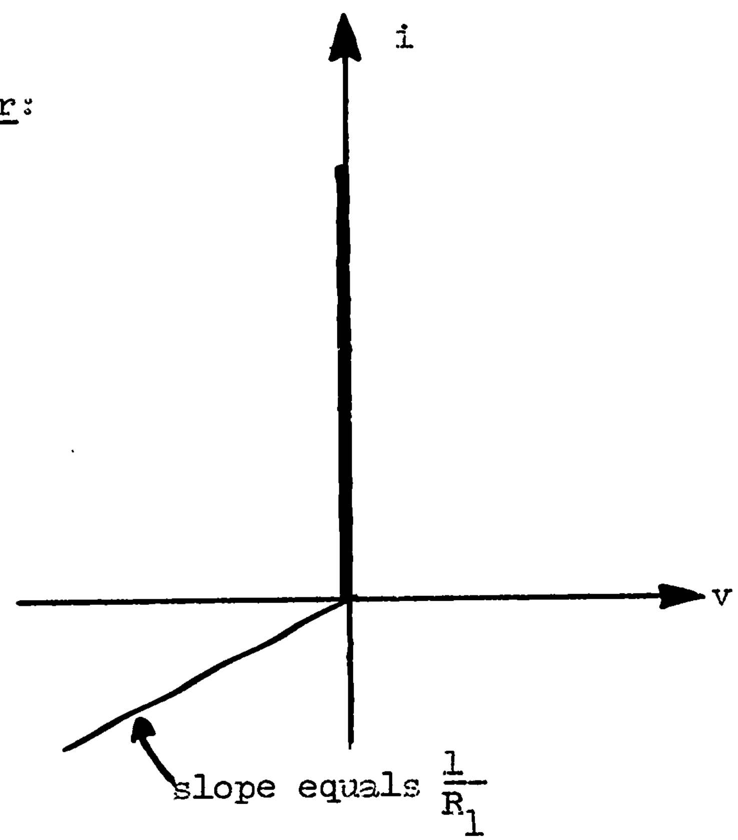
Figure 21

So far, we have the i-v characteristic of a piecewise linear model diode. The development of an equivalent circuit for the model diode is our next objective. It should be clear that what is required is a network which reduces to a resistance, equal to the forward resistance of the model diode, when the voltage is positive. Likewise, when the voltage is negative, the equivalent circuit must reduce to another resistance equal to the reverse resistance of the diode.

To start, consider the parallel combination of a resistor and an ideal diode shown in Fig. 21. Construct the i_1-v_1 curve of this network. (Note the definitions of i_1 and v_1.)

94

<u>Answer</u>:



Let us describe the i_1-v_1 behavior of the network of Fig. 21 in terms of forward and reverse resistances.

a) The forward resistance equals ____________ ohms.

b) The reverse resistance equals ____________ ohms.

96

<u>Answer</u>: a) The forward resistance equals <u>zero</u> ohms.

b) The reverse resistance equals <u>R_1</u> ohms.

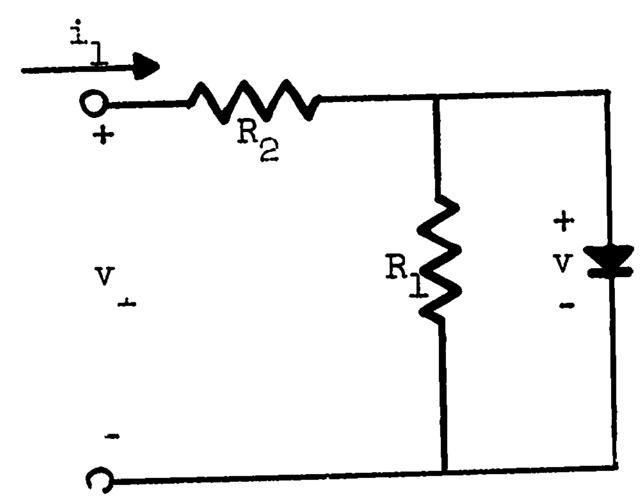


Figure 22

To achieve a non-zero forward resistance, let us modify the network by adding a second resistance in series, as indicated in Fig. 22. We see that when the diode is closed the network reduces to a resistance of R_2 ohms. However, when the diode is open, R_1 and R_2 become series connected. Hence, this network is equivalent to a sort of <u>two-state resistor</u>.

Complete the following:

a) The ideal diode is closed when v_1 is ______________.

b) The ideal diode is open when v_1 is ______________.

c) The forward resistance of the network equals __________.

d) The reverse resistance of the network equals __________.

<u>Answer</u>: a) The ideal diode is closed when <u>$v_1 > 0$</u>.

b) The ideal diode is open when <u>$v_1 < 0$</u>.

c) The forward resistance equals <u>R_2</u> ohms.

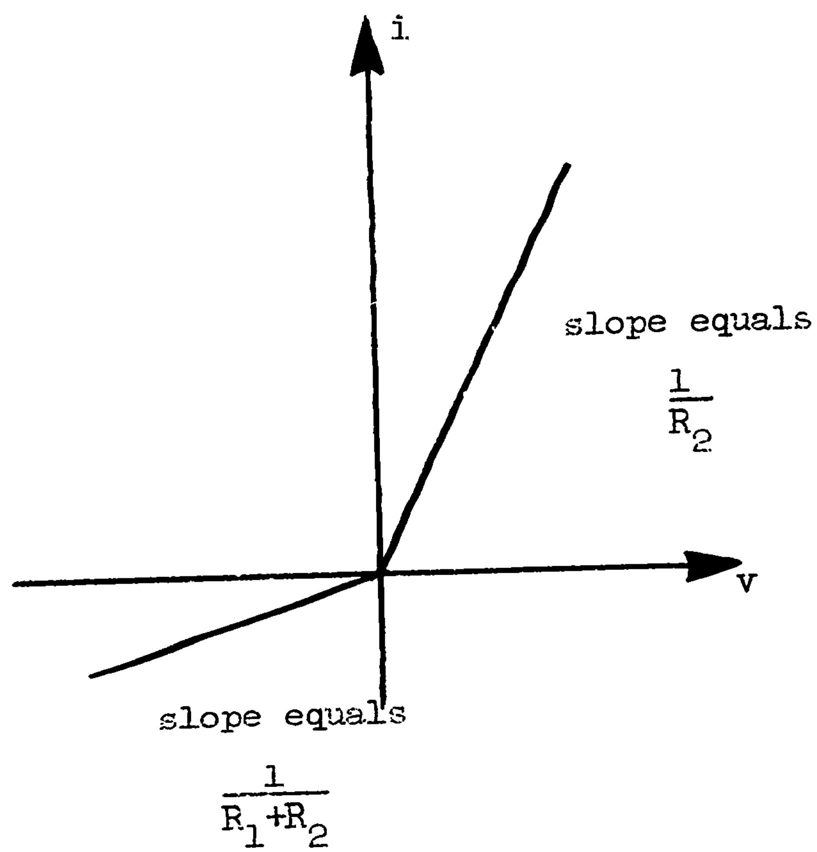
d) The reverse resistance equals <u>R_1+R_2</u> ohms.

The behavior of the network of Fig. 22 as a "two-state resistor" should now be clear. For one polarity of voltage, $v_1 > 0$, the network reduces to an equivalent resistance, R_2. However, for $v_1 < 0$, the network is equivalent to the larger resistance, R_1+R_2 ohms.

Construct the i-v characteristic curve for the network of Fig. 22, indicating the appropriate slopes.

100

Answer:



Comparison of this i_1-v_1 curve with that of the model diode, page 90, should now convince you that these two curves can be made identical by the proper choice of R_1 and R_2.

Determine expressions for R_1 and R_2 in terms of the forward resistance R_f and the reverse resistance R_r of the model diode so that the network of Fig. 22 is equivalent to the model diode.

102

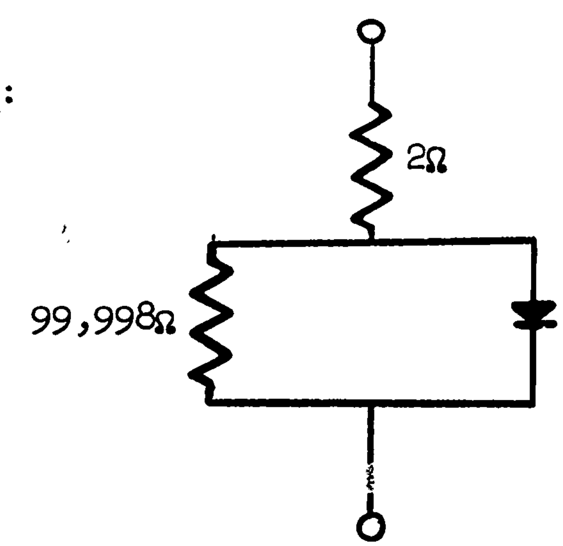
<u>Answer</u>: $R_1 = R_r - R_f$

$R_2 = R_f$

Suppose a certain diode has its i-v curve approximated by a model diode whose forward and reverse resistances are 2 ohms and 100,000 ohms, respectively. Draw an equivalent network for the diode and specify the resistance of each resistor.

104

<u>Answer</u>:



Remark:

These values of forward and reverse resistance are typical practical values. If anything, the ratio of reverse to forward resistance has been understated. We learn from this example that, when there is a large difference between the forward and reverse resistances, the resistor R_1 may be taken to equal R_r without appreciable error. This is almost always the case in practical situations.

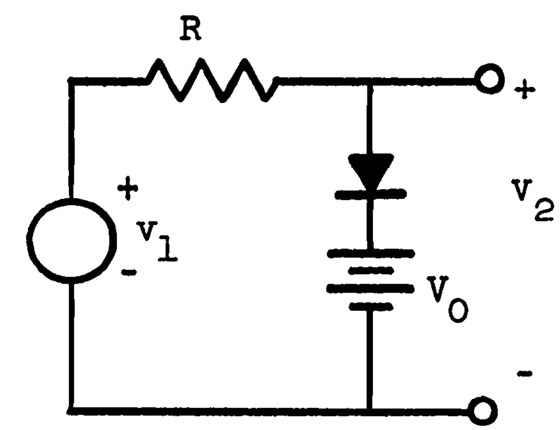


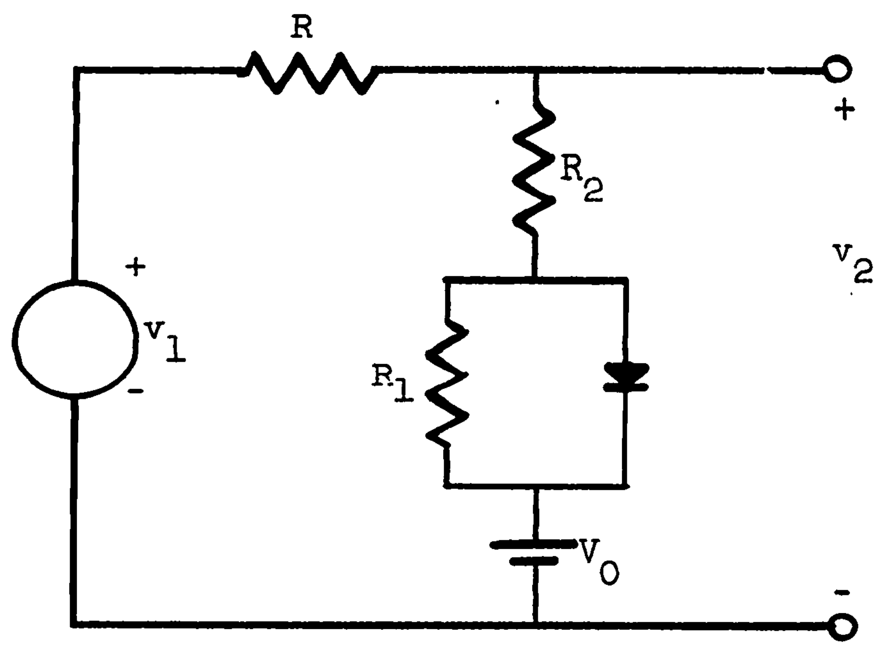
Figure 23

To illustrate the use of the model diode in making circuit calculations, let us return to the limiter circuit of Fig. 9. This time, however, we shall assume that an actual diode is used. The arrangement is indicated in Fig. 23. Once again, our interest will center on the variation of v_2 in response to a varying input voltage v_1.

The actual diode behavior will be represented by a model diode and calculations made using the equivalent circuit of the model diode. Redraw the network of Fig. 23, replacing the actual diode by its model diode equivalent circuit.

106

Answer:



As in the original limiter, the ideal diode in this equivalent network will be in one of two states: open or closed.

We must determine three things:

1) the relationship between v_1 and v_2 when the diode is open;

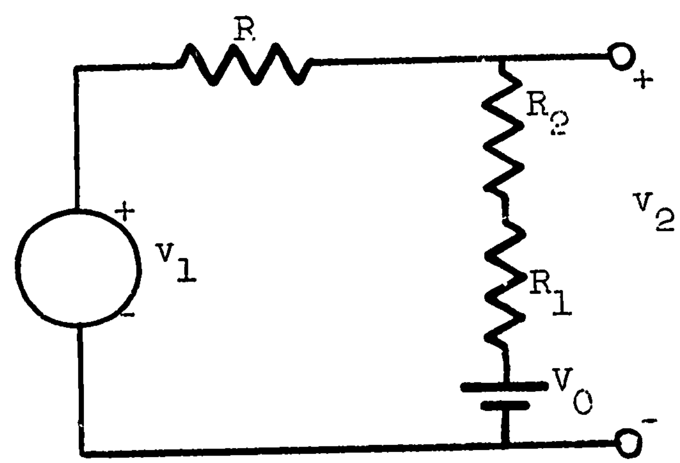
2) the relationship between v_1 and v_2 when the diode is closed; and

3) the <u>critical value</u> of v_1, the value at which the diode changes state.

First, consider the diode to be open. Draw the equivalent circuit and calculate both the ideal diode voltage, $\underline{v}$, and the output voltage, $\underline{v_2}$, in terms of v_1, V_0, and the three resistors.

108

<u>Answer</u>:



$$v = \frac{R_1}{R+R_1+R_2}(v_1 - V_0)$$

$$v_2 = \frac{R_1+R_2}{R+R_1+R_2} v_1 + \frac{R}{R+R_1+R_2} V_0$$

Remember that these expressions apply when the ideal diode is open, which means that the diode voltage v is ________. Hence, the critical value of v_1, at which the diode changes state, equals _______.

110

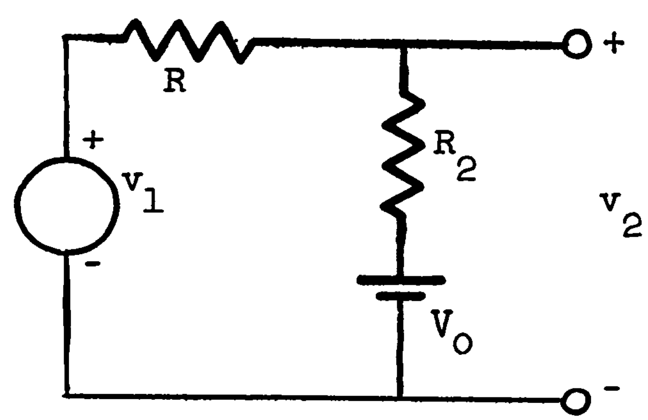
<u>Answer</u>: v is <u>negative</u>

v_1 equals $\underline{V_0}$

It remains to examine the network when the ideal diode is closed, which occurs when $v_1 > V_0$. Looking again at Fig. 23, draw an equivalent network with the diode closed and write an expression relating v_2 to v_1.

112

<u>Answer</u>:



$$v_2 = \frac{R_2}{R+R_2} v_1 + \frac{R\,V_0}{R+R_2}$$

To summarize, we have now obtained the following results:

$$v_2 = \frac{R_1+R_2}{R+R_1+R_2} v_1 + \frac{R}{R+R_1+R_2} V_0 \text{ when } v_1 \leq V_0$$

$$v_2 = \frac{R_2}{R+R_2} v_1 + \frac{R}{R+R_2} V_0 \text{ when } v_1 \geq V_0$$

Remembering that R_1 and R_2 are related to the forward and reverse resistances of the diode, rewrite these expressions in terms of the forward resistance R_f, and the reverse resistance, R_r.

<u>Answer</u>:

<u>When $v_1 \leq V_0$</u>:

$$v_2 = \frac{R_r}{R+R_r} v_1 + \frac{R}{R+R_r} V_0,$$

and, <u>when $v_1 \geq V_0$</u>:

$$v_2 = \frac{R_f}{R+R_f} v_1 + \frac{R}{R+R_f} V_0.$$

Let us rearrange these equations somewhat, as follows:

$$v_2 = \frac{1}{1+\frac{R}{R_r}} v_1 + \frac{1}{1+\frac{R_r}{R}} V_0, \text{ when } v_1 \leq V_0$$

$$v_2 = \frac{1}{1+\frac{R}{R_f}} v_1 + \frac{1}{1+\frac{R_f}{R}} V_0, \text{ when } v_1 \geq V_0.$$

Note the great similarity between these expressions, each of which defines a straight-line segment when v_2 is plotted against v_1. Observe how the respective slopes and intercepts differ.

Suppose we use as typical values: $R_r = 100{,}000\Omega$, $R_f = 2$, and $R = 2{,}000\Omega$.

a) As compared with the <u>slope</u> for $v_1 \leq V_0$ (diode open), the <u>slope</u> for $v_1 \geq V_0$ (diode closed) is about ________ times smaller.

b) As compared with the <u>intercept</u> for $v_1 \leq V_0$ (diode open), the <u>intercept</u> for $v_1 \geq V_0$ (diode closed) is about ____ times larger.

116

<u>Answer</u>: a) <u>about 1,000 times</u> smaller

b) <u>about 50 times</u> larger

With these typical values for orders of magnitude in mind, construct a plot of $\underline{v_2}$ against $\underline{v_1}$ using the literal expressions which are repeated below. Label the slopes and intercepts and critical value of $\underline{v_1}$.

$$v_2 = \frac{1}{1+\frac{R}{R_r}} v_1 + \frac{1}{1+\frac{R_r}{R}} V_0, \text{ when } v_1 \leq V_0$$

$$v_2 = \frac{1}{1+\frac{R}{R_f}} v_1 + \frac{1}{1+\frac{R_f}{R}} V_0, \text{ when } v_1 \geq V_0$$

Answer:

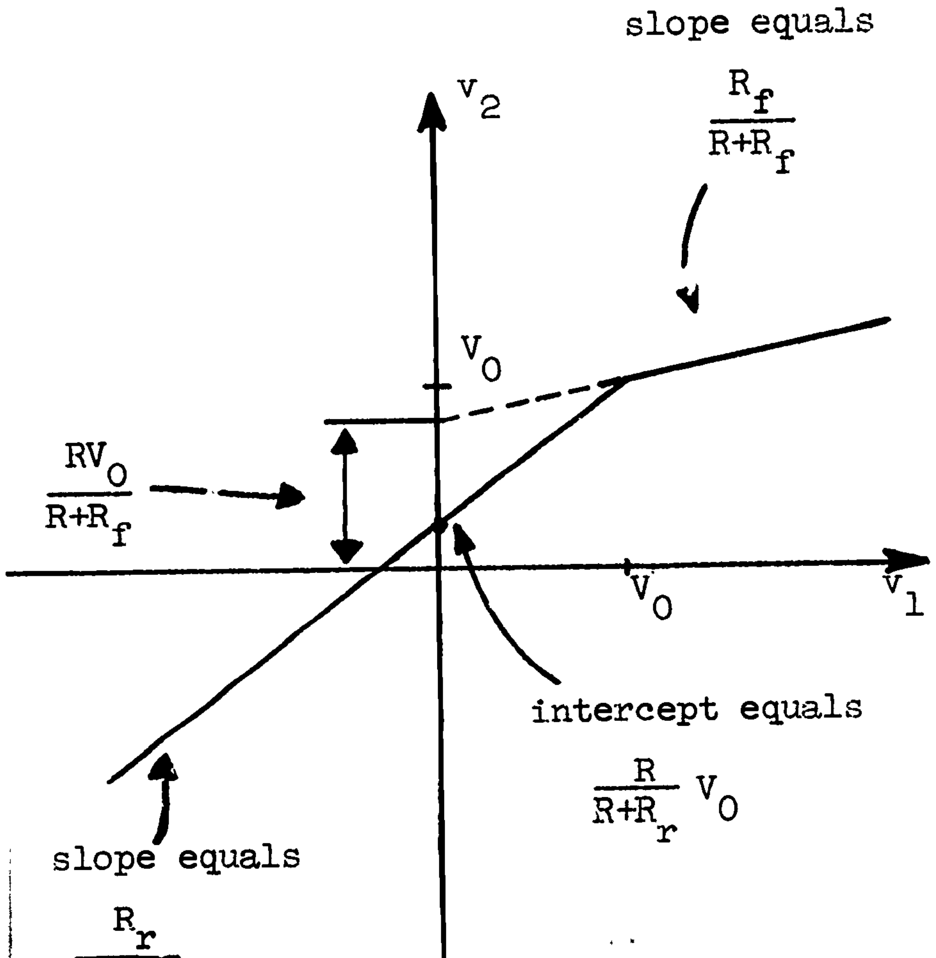


Figure 24

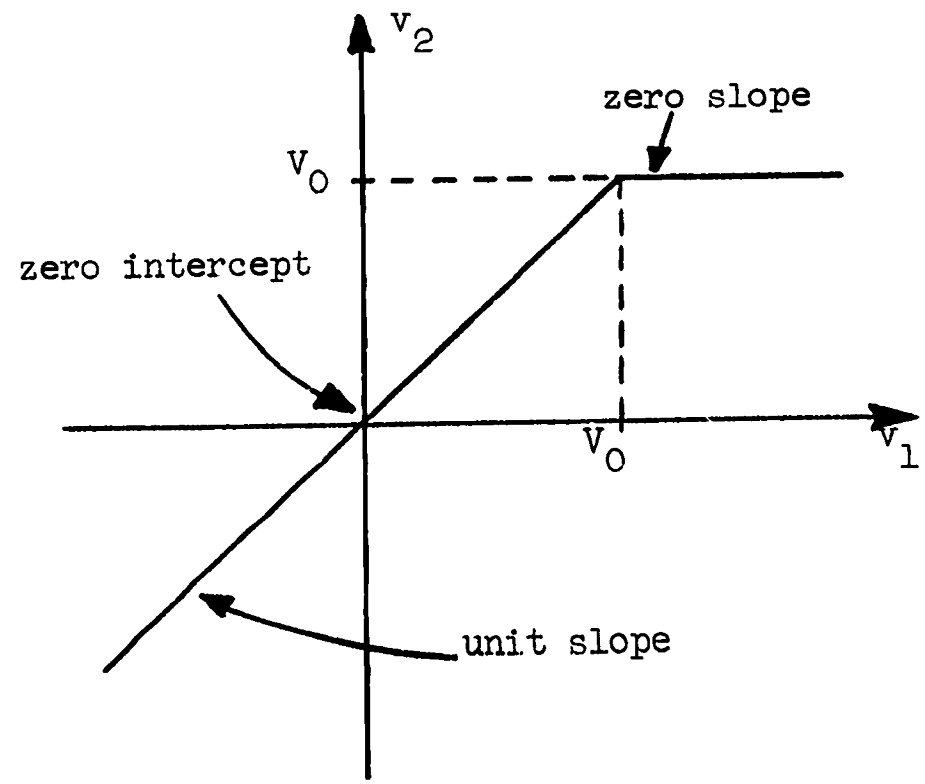


Figure 25

This is the output-input curve of the limiter when a model diode is used, instead of an ideal diode, to approximate the actual diode. This curve is to be compared with the output-input curve of a limiter circuit in which an ideal diode instead of a model diode is used. This curve is reproduced in Fig. 25.

Compare the ideal limiter curve of Fig. 25 with that of Fig. 24, and give the values for R_f and R_r that will change the curve of Fig. 24 into the curve of Fig. 25

R_f = ____________________.

R_r = ____________________.

120

<u>Answer</u>: $R_f = 0$ ohms

$R_r = \infty$ ohms

It is, of course, desirable that the limiter operate as close to the ideal as possible.

Consider each of the two regions in Fig. 24 and focus attention on the slope when the diode is open and on the (extrapolated) intercept when the diode is closed. From Fig. 24 the values are:

a) slope when diode is open: ________________

b) extrapolated intercept when diode is closed: ______________.

122

<u>Answer</u>:

slope: $\frac{R_r}{R+R_r}$

intercept: $\frac{R}{R+R_f} V_o$

The desired values for the slope when the diode is open and the extrapolated intercept when the diode is closed are, respectively, unity and V_0.

It follows that this condition requires that both:

a) $\frac{R_r}{R+R_r}$ equal ______________.

and

b) $\frac{R}{R+R_f}$ equal ______________.

124

<u>Answer</u>: a) <u>unity</u>.

b) <u>unity</u>.

To make the non-ideal limiter behave as closely as possible to the ideal limiter, it is necessary that both expressions $R_r/(R_r+R)$ and $R/(R+R_f)$ be as nearly equal to unity as possible.

Considering that R_r and R_f are fixed by the nature of the diode, what are the restrictions placed upon the resistor R by the above conditions?

126

<u>Answer</u>: $\frac{R_r}{R_r+R} \longrightarrow 1$ requires $R \ll R_r$

$\frac{R}{R+R_f} \longrightarrow 1$ requires $R \gg R_f$

3

The first of these conditions requires R to be a small number, while the second requires R to be a large number. Taken to the limit, these conditions are incompatible, but because of the wide range between R_f and R_r, a suitable value of R can be found. For example, if the forward and reverse resistances are 2 and 100,000 ohms, respectively, the above conditions require that

$2 \ll R \ll 100{,}000$ ohms.

A good compromise is obtained by requiring that R be chosen so that each of the expressions approaches unity to the same degree. Impose this compromise condition and solve for the resultant R in terms of R_f and R_r.

128

<u>Answer</u>: $\frac{R_r}{R_r+R} = \frac{R}{R+R_f}$

$$R = \sqrt{R_r R_f}$$

In order to get a feeling for orders of magnitude, assume the forward and reverse resistances of the diode to be 2 and 100,000 ohms. Calculate the value of R that will satisfy the compromise condition.

130

<u>Answer</u>: $R = \sqrt{2 \times 10^5} \doteq 447$ ohms.

This is certainly much greater than 2 ohms and is nowhere near as large as 100,000 ohms.

The linearized model diode has been introduced as a sort of compromise. Calculations made with this model will not yield the exact answers; however, we may expect the results to be close estimates of exact behavior. Our gain in accepting this model is a considerable reduction in the amount of computational work to secure answers. Our loss is, of course, a reduction in the accuracy of the answers.

Because you have been working so very hard, we will give you a rest and not call for any response to this frame.

Summary for Section II

Complete <u>all</u> of the following before checking your answers:

1) In order to represent actual diode behavior with a model that is more realistic than the _______ ________ model, another scheme has been devised which accounts for the small voltage in the ________ direction and the small _________ in the reverse direction.

2) This better model is called the _______ _______ ________ diode, which we designate more briefly as the <u>model diode</u>.

3) The main reason for using linear segments to approximate the diode i-v curve is ____.

4) The model diode has an equivalent circuit consisting of two ___________ and one _________ ___________.

5) The equivalent circuit for the model diode is used in circuit calculations in the same general way as before. Each of the _______ possible states of the model diode must be considered. The critical values of the circuit variables causing the model diode to ______ ________ must be determined.

<u>Answer</u>: 1) <u>ideal diode</u>

<u>forward</u>

<u>current</u>

2) <u>piecewise linear model</u>

3) the great ease of calculation afforded by such straight-line segments.

4) two <u>resistors</u> and one <u>ideal diode</u>.

5) ... <u>two</u> possible ...

... to <u>change state</u> ...

DIODES AND DIODE CIRCUITS

Section III

We continue our discussion with a consideration of some techniques for the <u>exact</u> solution of a network containing a diode. Up until now, we have represented an actual diode by the idealized and oversimplified models, e.g., the <u>ideal diode</u> and the <u>piecewise-linear diode</u>. In the case of each of these two models, only some of the features of the actual diode are accurately represented. The simplest model, the ideal diode, takes into account only the switch-like character of the actual diode. The piecewise-linear diode constitutes a further refinement and includes the additional effects of small forward voltage and small reverse current. These models are very useful and are often used in the analysis of diode circuits. However, neither one provides the exact representation of an actual diode and thus answers they yield are necessarily only approximate.

Because the actual diode i-v curve is not linear, there is no equivalent circuit consisting of constant resistors and ideal diodes. The previous methods of analysis are inapplicable. Determination of the exact solution of this

non-linear problem requires a new attack and it is to this end that our efforts will be directed in this section.

When you complete this section, you will be able to compute the current, voltage, or power in any element of a network containing resistors, sources, and a single diode. The techniques are essentially graphical and they will yield answers without approximation. Also included will be a consideration of power dissipation within the diode and the control of this dissipation by proper choice of the other elements in the network.

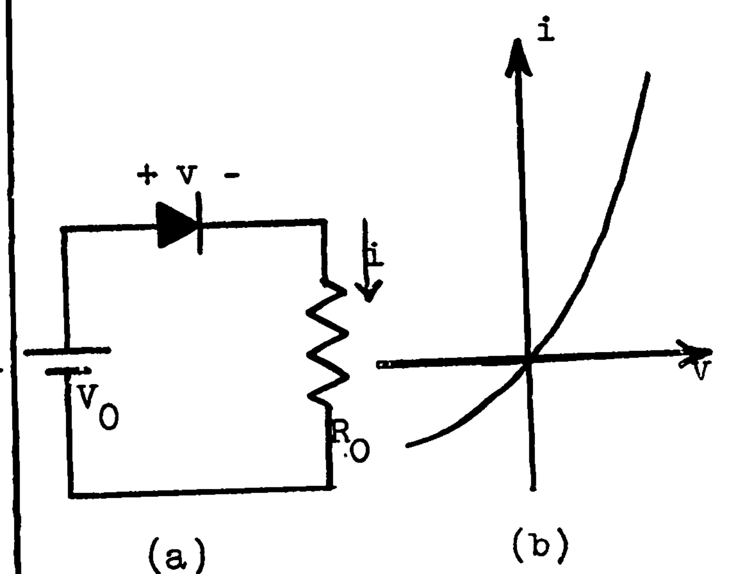


Figure 26

To get some idea of the problem presented by the presence of a non-linear element, let us consider the simple arrangement of Fig. 26(a), containing a non-linear diode whose i-v curve is given in Fig. 26(b).

Assume the diode i-v curve is given in full detail, along with the numerical values of V_0 and R_0. Can you write a single equation that gives the current, i, explicitly in terms of only the known quantities? It so, write the equation now.

138

Answer: Since there is no simple way of expressing the diode i-v curve in terms of an equation, it is not possible to write a single equation that expresses i explicitly in terms of known quantities.

Refer again to the circuit of Fig. 26(a). The i-v curve of Fig. 26(b) is the graphical representation of one relation between v and i, the diode current and voltage.

These quantities are also under the influence of the voltage source, V_0, and the resistor, R_0. Can you write an equation involving the diode current and voltage that reflects the influence of V_0 and R_0? If so, do it.

140

<u>Answer</u>: $v = V_0 - iR_0$

(This equation may take several different forms and still be correct.)

Thus, the circuit connected to the diode requires the diode voltage and current to satisfy the equation, $v = V_0 - iR_0$. However, this equation contains two unknowns, namely $\underline{v}$ and $\underline{i}$, and therefore is not enough, by itself, to determine $\underline{v}$ and $\underline{i}$ uniquely.

Clearly a second independent relation is required before the unique solutions can be obtained. What is this second relation?

142.

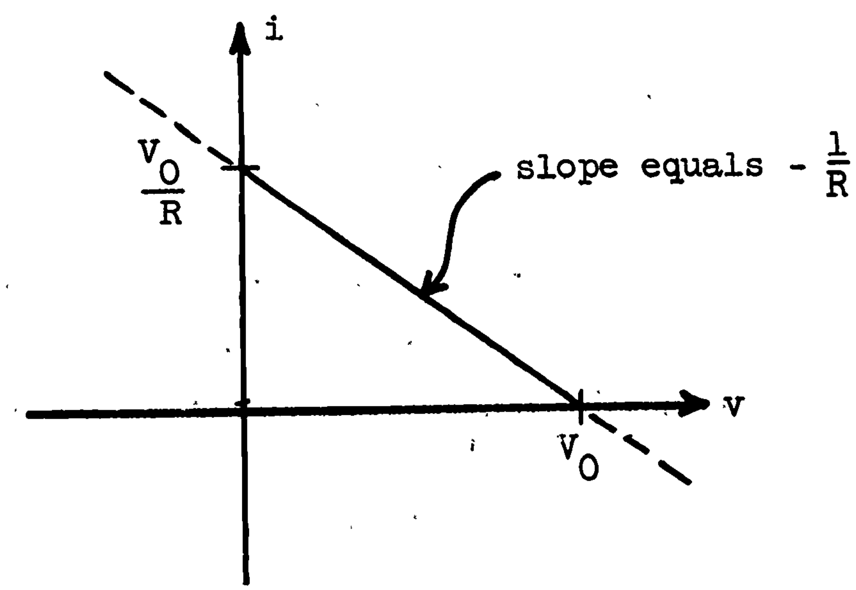
Answer: The *i-v* curve of the diode, Fig. 26.

Hence, $\underline{v}$ and $\underline{i}$, the diode current and voltage, are required to satisfy two relationships simultaneously. One is the $\underline{i}$-$\underline{v}$ curve of the diode. The second is the equation, $v = V_0 - iR_0$, which the external circuit requires. The problem is how to find the solution satisfying both relations. If the equation of the diode i-v curve were known, perhaps an algebraic procedure could be used. However, this equation is unknown and, in any event, would probably be too complicated for this purpose. Therefore, the only alternative, since we cannot convert the $\underline{i}$-$\underline{v}$ curve of the diode to algebraic form, is to convert the relation $v = V_0 - iR_0$ to graphical form.

Plot the curve of $\underline{i}$ vs. $\underline{v}$ resulting from the above equation. Label the plot with slope and intercept values.

144

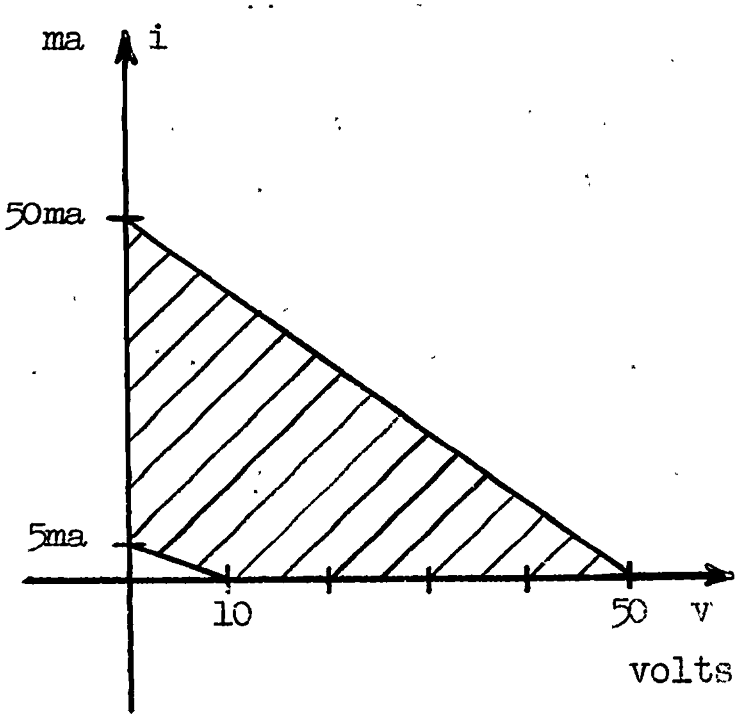
Answer:



Thus, it is clear that this line is completely specified by the voltage source and the resistor. Furthermore, the line does not have any direct dependence upon the diode. For ease of reference, we shall refer to this line as the <u>load line</u>. The name "load line" derives from the fact that in many practical applications the resistor, R_0, represents the part of the circuit to which the useful power is fed, i.e., the circuit load.

Suppose that R_0 is permitted to range over the values defined by $1{,}000 \leq R \leq 2{,}000$ ohms. Similarly, suppose the source voltage is confined in accordance with the expression $10 \leq V_0 \leq 50$ volts. Shade that portion of the first quadrant of the *i-v* curve which is the locus of all load lines satisfying these conditions.

Answer:



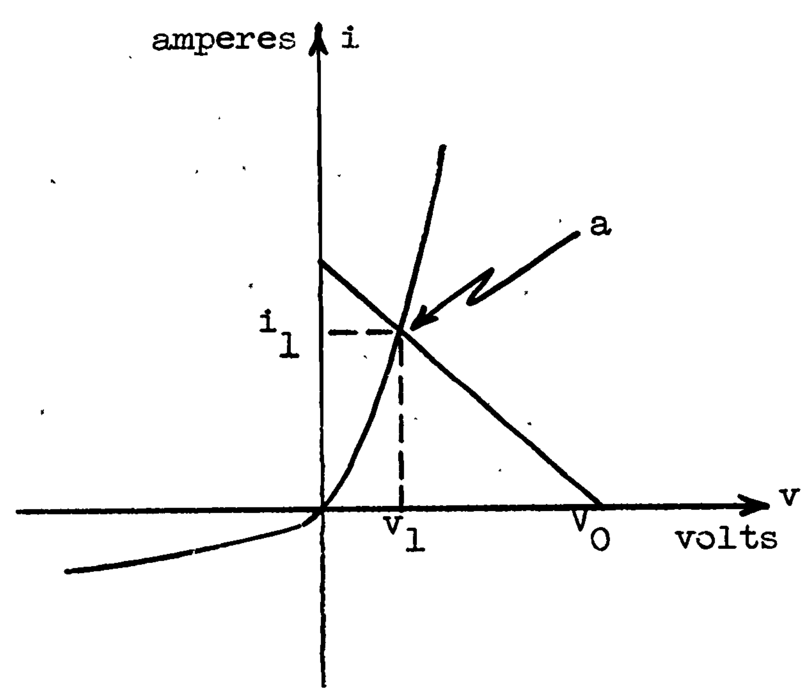


Figure 27

If the relation imposed by the circuit, $v = V_0 - iR$, is plotted on the same axes as the i-v curve of the diode, the result will have the general form of Fig. 27. Typically, there will be one point of intersection, marked a, which is common to both the straight line and the diode curve. This one point is the only one satisfying both relations. The coordinates of the point therefore yield the solution to the problem.

In terms of the labels on Fig. 27

a) the diode current is ________________.

b) the diode voltage is ________________.

c) the voltage across the resistor is ________________.

<u>Answer</u>: a) the diode current is <u>i_1</u>.

b) the diode voltage is <u>v_1</u>.

c) the voltage across the resistor is <u>$V_0 - v_1$</u>.

(You may have gotten $v_1 - V_0$ if you chose the opposite reference for the resistor voltage.)

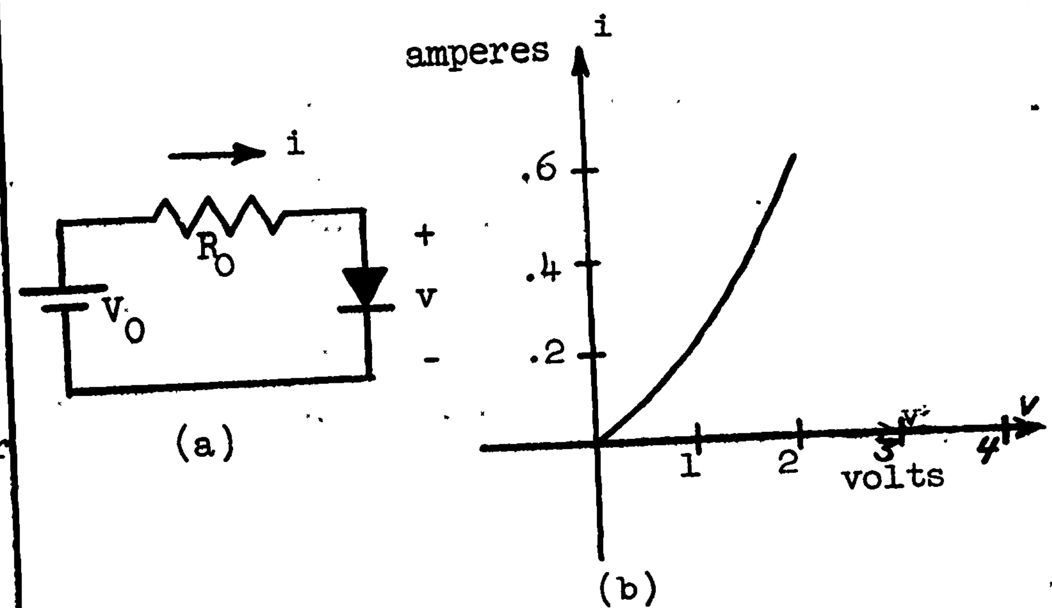


Figure 28

For additional practice, consider the circuit and diode $\underline{i}$-$\underline{v}$ curve, Fig. 28.

Determine each of the following:

a) $\underline{i}$ and $\underline{v}$ if $V_O = 3$ volts and $R_O = 6$ ohms;

b) R_O and $\underline{v}$ if $V_O = 4$ volts and $i = 0.3$ amps.;

c) V_O and $\underline{i}$ if $R_O = 10$ ohms and $v = 1$ volt.

150

<u>Answer</u>: a) $i = 0.3$ $\qquad v = 1.3$

b) $R_0 = 2.1$ $\qquad v = 1.3$

c) $V_0 = 3.1$ $\qquad i = 0.21$

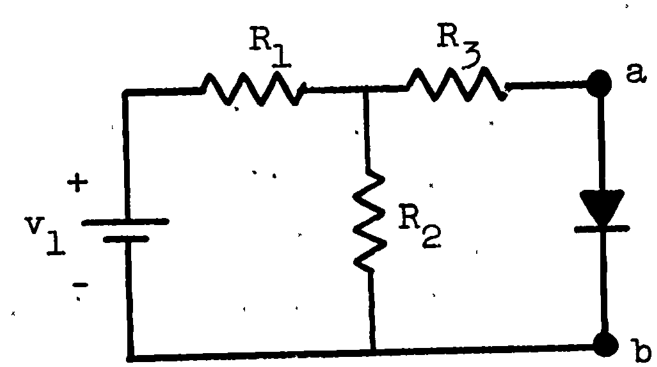
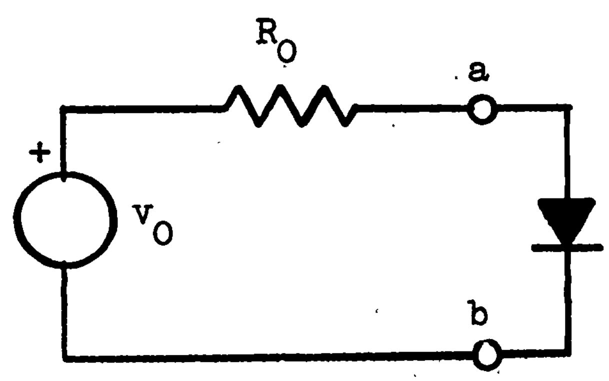


Figure 29

You now know how to solve for the current in a series circuit containing a diode, a voltage source, and a resistor. As a matter of fact, you can use the same technique to solve problems of a much broader class than the simple series circuit. This is because a network containing a single diode is often very easily reduced to an <u>equivalent series network</u>.

For example, consider the network of Fig. 29. Viewing the rest of the network from the terminals of the diode, reduce it to an equivalent series connection of a voltage source V_0 and a resistor R_0. Express the value of the single equivalent voltage source in terms of the original elements. Do the same for the single equivalent resistor. What name is common for the equivalent resistor-voltage-source combination?

<u>Answer</u>: called the "<u>Thevenin equivalent</u>"



$$R_0 = R_3 + \frac{R_1R_2}{R_1+R_2}$$

$$v_0 = \frac{R_2}{R_1+R_2}\,v_1$$

Note: The easiest solution to this problem is obtained by making several transformations between voltage source equivalents and current source equivalents, starting with R_1 and v_1.

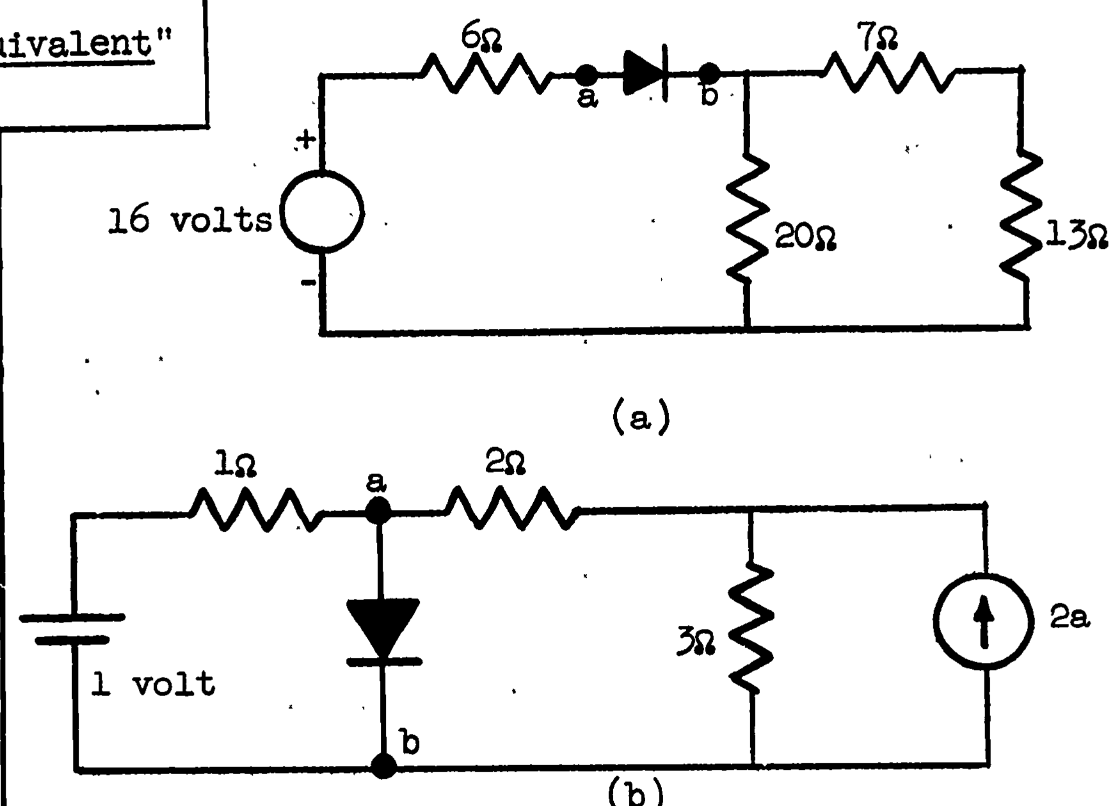
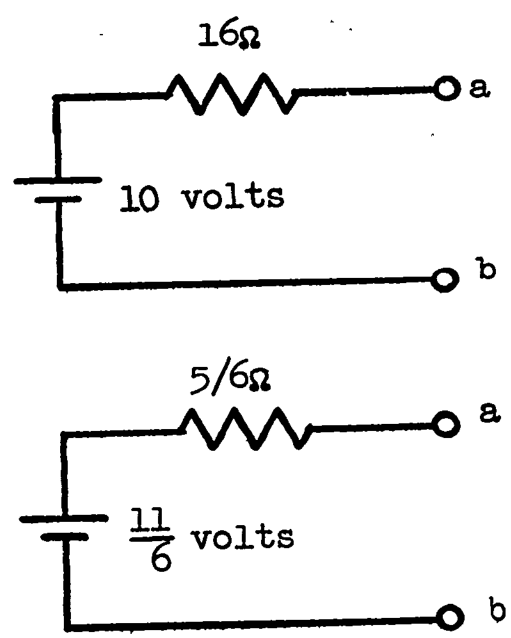


Figure 30

In Fig. 30 are networks, each containing a single diode along with diodes and sources.

In each case, view the rest of the network from the diode terminals, a-b, and reduce the remaining elements to a Thevenin equivalent. Determine the numerical values of the equivalent resistances and voltages.

Answer:



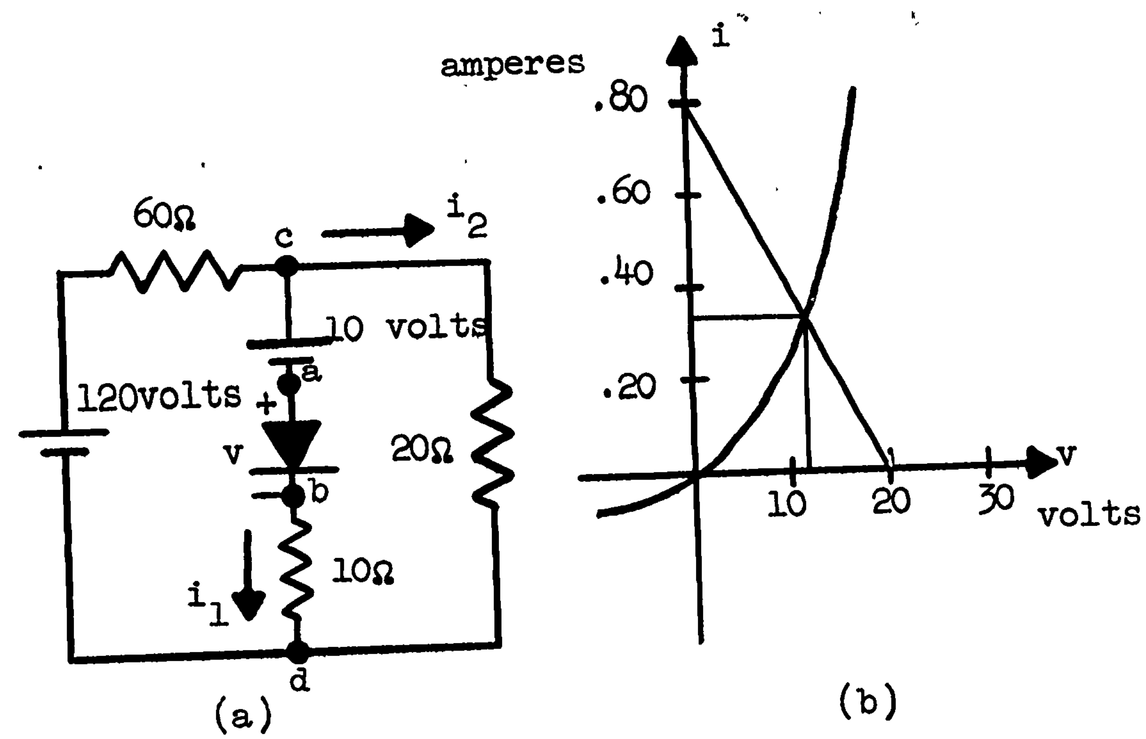


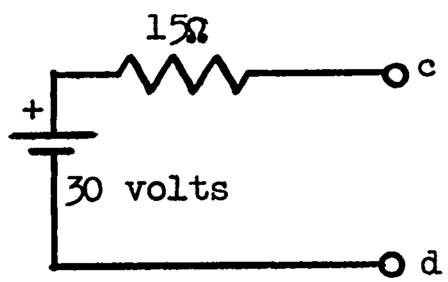
Figure 31

The network of Fig. 31(a) contains a single diode whose *i-v* curve is given in Fig. 31(b).

First, let us calculate the values of i_1 and *v*, the diode current and voltage. This can be done by reducing the network that is connected to the diode to a Thevenin equivalent (i.e., a series connection of R_0 and V_0). It is convenient to do this in two steps. Consider the terminals *c* and *d*; ignoring the entire branch containing the diode, reduce the remainder to a simple Thevenin equivalent. Calculate the numerical values of V_0, and R_0, in the equivalent network.

156

Answer:



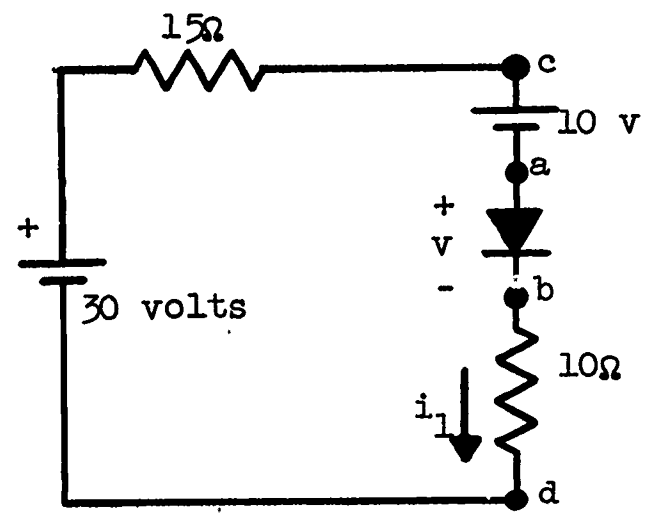


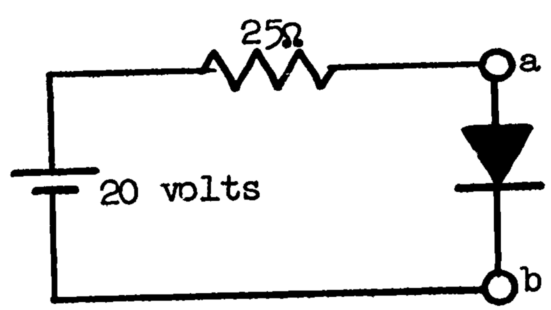
Figure 32

The branch containing the diode may now be returned to the rest of the network, which is now represented by the Thevenin equivalent. The result is indicated in Fig. 32.

View the network from the terminals a-b and reduce it to a simple series-equivalent connection of a resistor and a voltage source.

158

Answer:



The current i_1 and the voltage v can now be determined easily by drawing the load line on the i-v curve for the diode, Fig. 31(b). Do this and state the values of i_1 and v.

160

<u>Answer</u>: i_1 = 0.35

v = 12

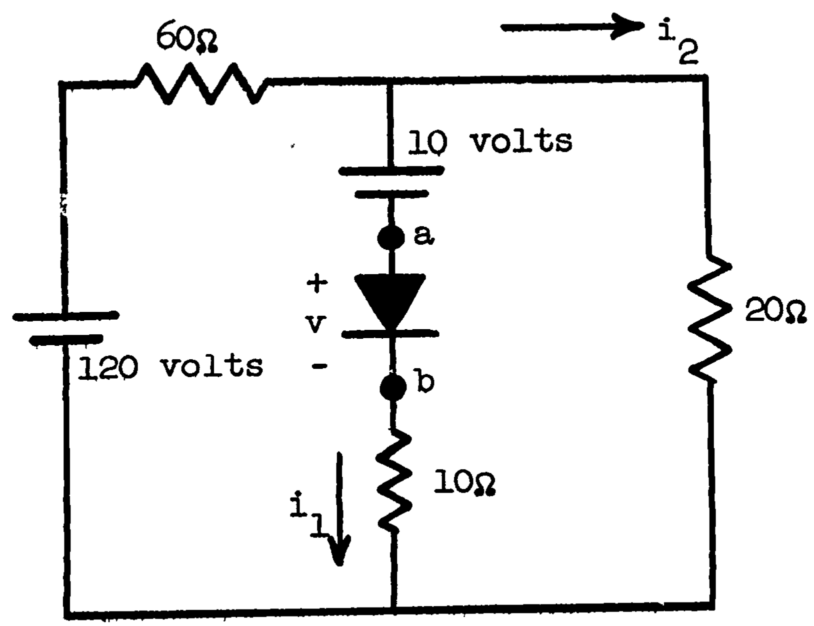


Figure 31(a) (repeated)

Refer again to the network of Fig. 31(a). Suppose that the current i_2 is required. It is clear that, while i_2 is not the diode current, the value of i_2 does depend upon the diode and its i-v curve. This is a case of determining the effect of a non-linear element upon the current somewhere else in the network.

Remember that i_1 and v are now known quantities. Calculate the value of i_2 using whatever approach you like.

<u>Answer</u>: Two approaches are presented below in the form of two equations which yield the value of i_2.

a) $120 = 60(i_1+i_2) + 20i_2$

b) $20i_2 = 10 + v + 10i_1$

When these equations are solved, the result is: $i_2 = 1.275$ amp.

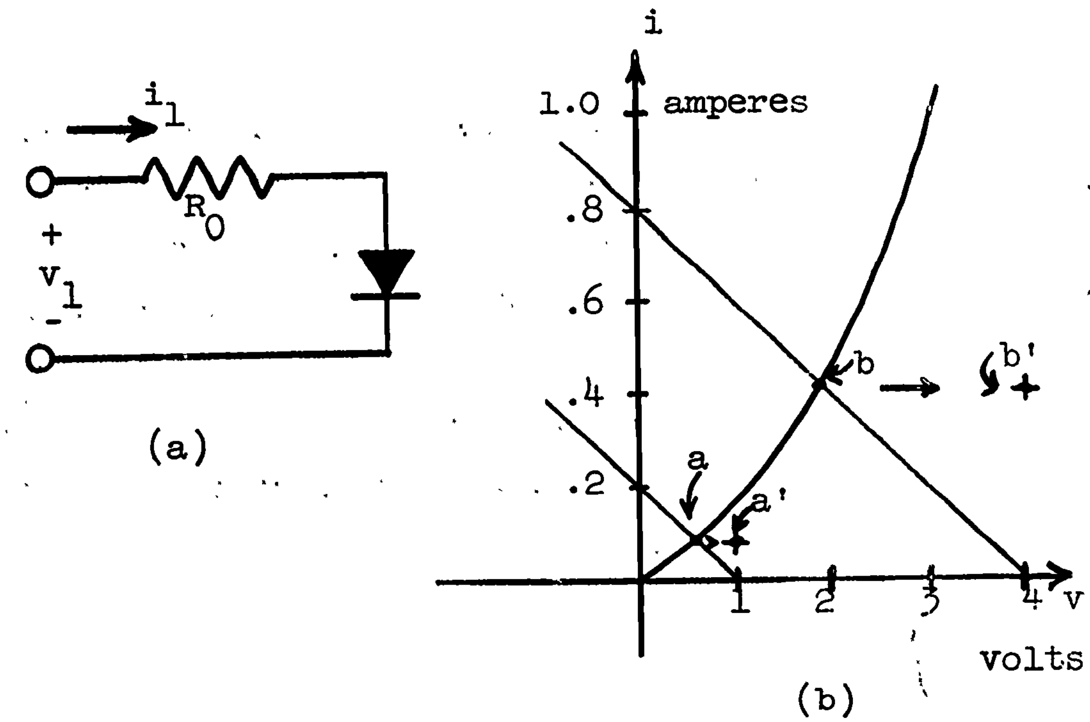


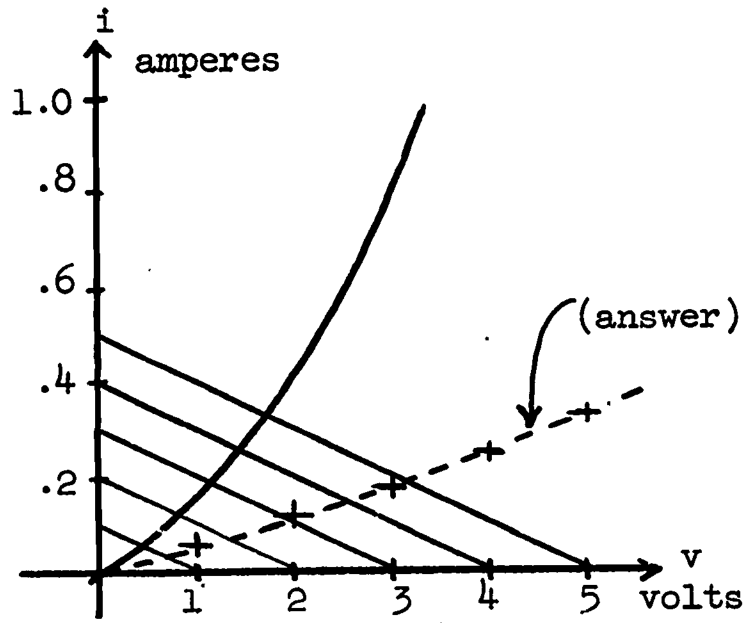
Figure 33

Sometimes the i_1-v_1 curve for the network of Fig. 33(a) is required. It can be constructed directly on the i-v curve of the diode in the following manner. Suppose R_0 equals 5 ohms. To find i_1 corresponding to $v_1 = 1$ volt, draw the load line of slope $-\frac{1}{5}$, intersecting the voltage axis at $v = 1$. The resultant current is indicated in Fig. 33(b) by the point <u>a</u>. Since this current occurs when v_1 equals 1, it can be plotted directly above the point $v = 1$, point a'. To determine the current for $v_1 = 4$, the load line is moved parallel to itself until it intersects the $v = 4$ point on the voltage axis. The intersection <u>b</u> is then translated to a position directly above $v = 4$, <u>b'</u>. Repetition of this procedure will yield the entire locus of i_1-v_1.

Construct the i_1-v_1 curve for $R_0 = 10$ ohms.

164

Answer:



Up until now a very important and practical feature of the real diode, namely, the dissipation of power, has not been considered. The dissipation of power in an electrical device results in a temperature rise. Because such devices operate properly only when the temperature does not exceed certain limits, it is necessary to provide a <u>maximum power-dissipation rating</u> for each device. When the actual power dissipation does not exceed this maximum, the device can be expected to operate in the proper way.

Return to the network of Fig. 31(a) and calculate the power dissipated by the diode.

<u>Answer:</u> $p = i_1 v$

$= (0.35)(12)$

$P = i_1 v = (0.35)(12) = 4.2$ watts

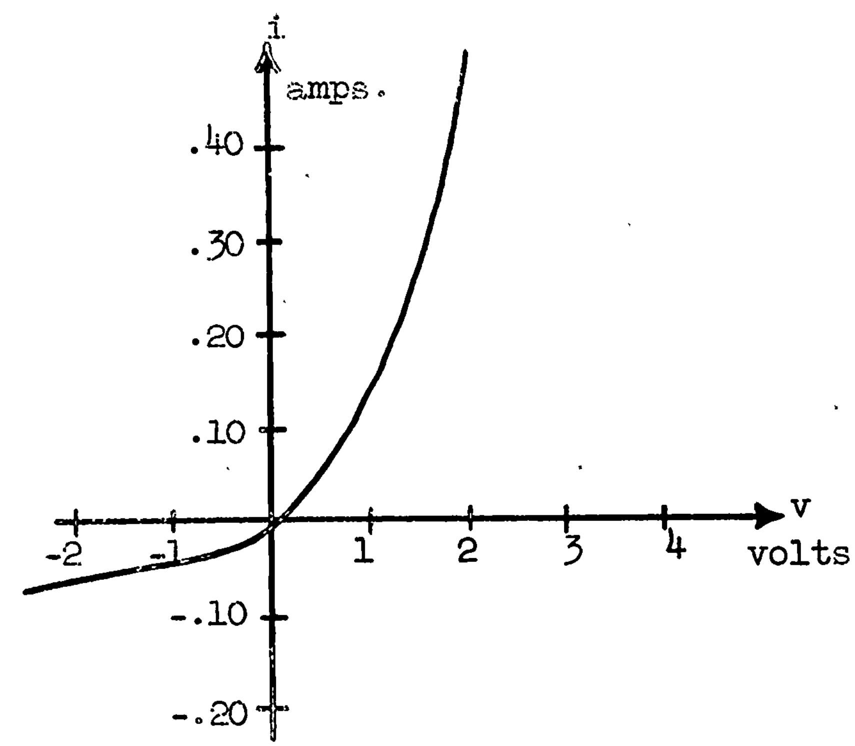


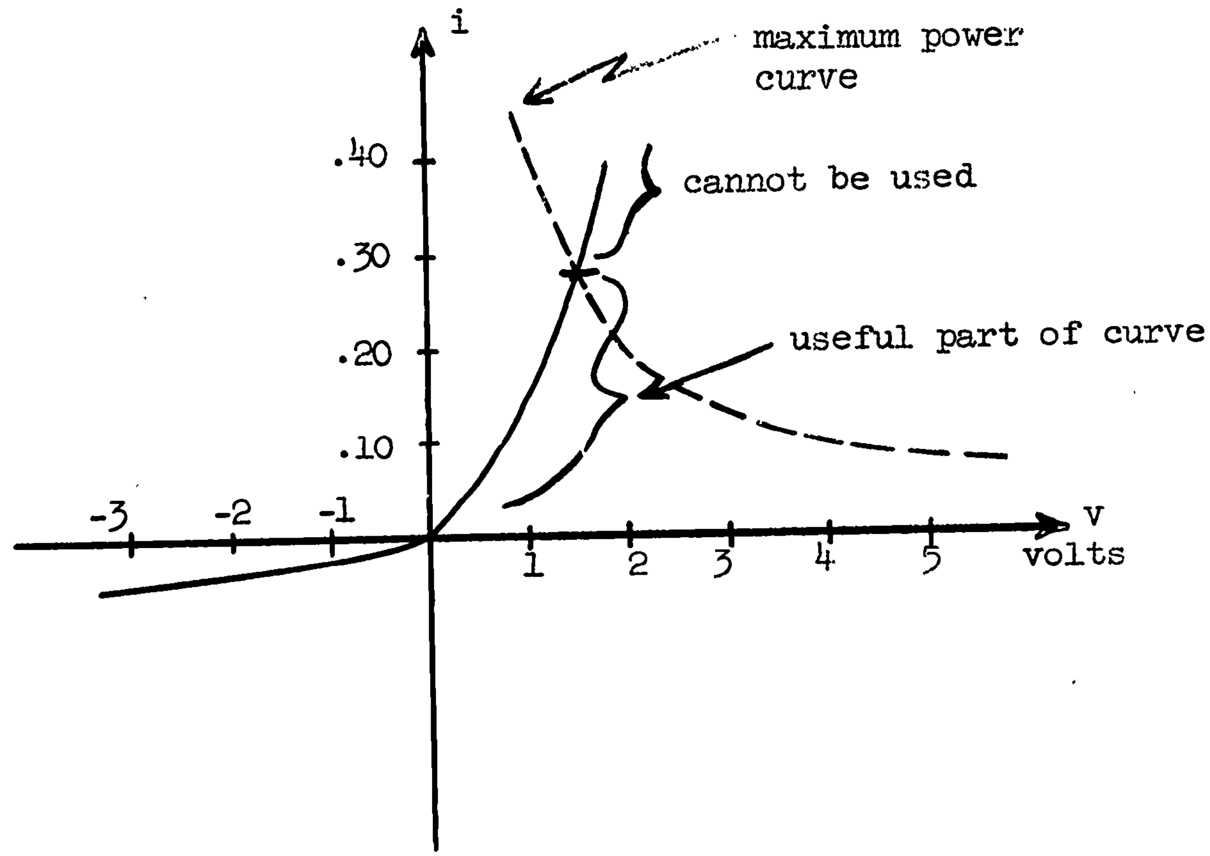
Figure 34

Since instantaneous power dissipation equals the product of the voltage and current, limiting this power is equivalent to restricting the range of the $\underline{i}$-$\underline{v}$ curve of the diode over which operation may take place. The nature of this restriction is conveniently displayed by plotting the relation between $\underline{i}$ and $\underline{v}$ resulting from the power restriction, i.e., $P_{max} = i\ v$.

Using the diode plot of Fig. 34, construct directly on this plot the maximum power dissipation curve. Assume that $P_{max} = 0.400$ watts for this case. What type of curve is this? Label the region of the diode curve that may be used without danger to the diode.

168

<u>Answer</u>:



The curve is a hyperbola.

Refer again to the diode whose i-v plot is on page 168.

a) Suppose that a time varying voltage source is connected in series with an 8 ohm resistor and this diode. What is the maximum value in volts that the voltage source may have without causing excessive power dissipation in the diode?

b) If the source voltage is limited to 2.5 volts, what is the minimum value of series resistance necessary to prevent excessive dissipation in the diode?

170

<u>Answer</u>: a) v_{max} = 3.75 v

b) R_{min} = 3.5Ω

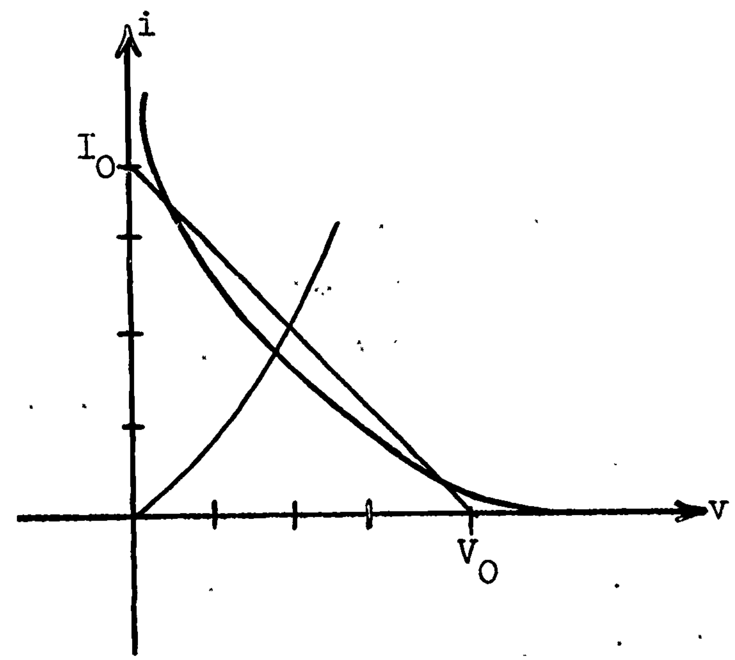


Figure 35

In Fig. 35 are shown the i-v plot and the maximum-power hyperbola for a given diode. For the load line drawn there is clearly an excessive power dissipation in the diode.

a) Suppose that the voltage V_0 is held constant and the series resistance increased until the diode dissipation is reduced to the maximum permissible. What percentage increase in R is required?

b) Instead of increasing R, the diode power may be reduced by lowering V_0. What per cent reduction in V_0 is necessary so that the diode dissipates exactly the maximum permissible power?

172

<u>Answer</u>: a) 28%

b) 25%

Summary:

Fill in all blanks before checking answers.

1. In this section we learned how to calculate quantities in networks containing resistors and one non-linear diode, using a graphical construction.
2. The method involves superimposing the ________ ________ directly on the diode i-v curve.
3. The coordinates of the point of intersection between the ________ curve and ________ line equal the diode current and voltage.
4. In general, the rest of the network, exclusive of the diode, must be reduced to a series equivalent connection of a ____________ and a ____________.

<u>Summary</u> (continued)

5. The power dissipation in a diode must be ______________ to prevent damage from excessive temperature rise.
6. The maximum-power hyperbola is a plot of the equations: ______________________.

<u>Answers</u>:

1)
2) <u>load line</u>
3) <u>diode</u> curve and <u>load</u> line ...
4) <u>resistor</u> and a <u>voltage</u> source
5) must be <u>limited</u>
6) $vi = P_{max}$